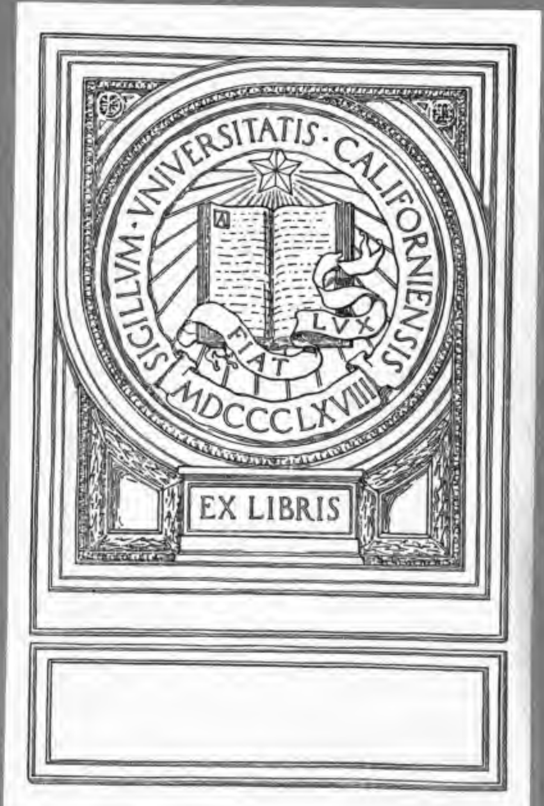
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ELEMENTARY ELECTRO-TECHNICAL SERIES

ALTERNATING ELECTRIC CURRENTS

BY

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PREFACE

In preparing this little volume on *Alternating Electric Currents*, as one of a series entitled the *Elementary Electro-Technical Series*, the authors believe that they are meeting a demand, that exists on the part of the general public, for reliable information respecting such matters in electrical knowledge as can be readily understood by those not specially trained in electro-technics.

The subject of alternating-electric currents is, to-day, perhaps, the most prominent in the electrical engineering field. Although when profoundly treated, the subject is so extremely technical as not only to necessitate the use of advanced mathematics but also to require, on the part of the student, considerable knowledge of electricity, yet the authors feel

confident that a considerable portion of the subject can readily be understood by the general public. They therefore offer this volume, with the belief that since the commercial applications of alternating currents are rapidly becoming so important, it is no longer a question of willingness, but of necessity, on the part of the general public, to become familiar with the outlines of this branch of electro-technics.

CONTENTS

ALTERNATING ELECTRIC CURRENTS.

CHAPTER I.

INTRODUCTORY.

In a river, far enough above its mouth to lie beyond the reach of tidal influences, the water constantly flows in one direction; namely, down stream, or from the source toward the mouth. Farther down the river, within the tidal limits, the direction of flow alternates, or is reversed four times in about twenty-four hours: the water flowing alternately up stream

for about six hours, and down stream for about six hours.

In continuous electric currents, the electric flow is unidirectional; *i.e.*, takes place continuously in one direction through the conducting channel, like a river above the tideway. In alternating-electric currents the direction of flow in the conducting circuit, or electric channel, is alternately reversed, like a river within the limits of tidal influence.

In a river, the current, or flow of water, changes direction but four times in every 24 hours; that is, during this time there are four alternations or changes of direction. In an alternating-electric circuit, the alternating-electric current, or flow of electricity, changes direction, or is reversed, many times per second. The number of

alternations per second is commonly called the *frequency of alternation*. In practice, the frequency of alternation is from 50 to 270; or, in other words, in practical alternating-current circuits, the electric current makes from 50 to 270 alternations per second, according to the system of machinery employed. But the frequencies of alternating currents may, under certain circumstances, greatly exceed 270 alternations per second.

In the case of telephonic circuits, over which articulate speech is transmitted, alternating-electric currents are employed, the frequency of which may be 1000 or more alternations per second. In the experiments of Tesla, in which special effects called *Tesla effects* are produced, extraordinarily high frequencies are employed, reaching sometimes millions of alternations in each second of time.

Recent investigations have shown that light is, in all probability, an effect produced in space by alternating-electric currents of frequencies reaching as high as 800 trillions per second.

In the case of a tidal stream, the time required for the flow of water to return to the condition it had at any moment, may be called the period of the stream. Thus, suppose a river at high water is just beginning to ebb; then a period will include the time required to again reach high water, and will embrace the time of one full ebb and one full flood; in this case, about 12 hours. During one period the flow of water in the river will have completed one cycle, and will have undergone two alternations, or reversals of direction. Every complete cycle, therefore, consists of two alternations. In the case of the

river, the duration of ebb and flood are unequal. In the case of all practical alternating currents, the duration of each reversal or alternation is the same.

The *period* of an alternating-electric current is the time required to complete two alternations, or, in other words, to effect one complete *cycle.* The number of cycles per second is called the *frequency.* The time occupied in each reversal is sometimes called a *semi-period.* Consequently, an electric current, making 100 reversals or alternations per second, would have a frequency of 100 alternations, or 50 complete cycles, per second.

In the case of most tidal streams, the water rises or falls at a comparatively uniform rate; that is, if the range of the tide is six feet, and the difference of level pro-

duced during ebb or flood is rigorously one foot per hour, then the level of the water in the river, at any time, might be graphically represented as in Fig. 1, where we assume that at noon, each day, high water occurs three feet above the mean level; at 3 P. M. the mean sea level is reached; at 6 P. M., low water; at 9 P. M.,

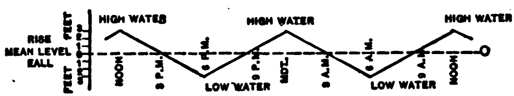


FIG. 1.—TIDAL FLOW OF RIVER.

mean level, and at midnight, high water, completing the cycle in a period of 12 hours. In this ideal case, the water is flowing from noon to 6 P. M. and from midnight to 6 A. M. out of the river, at a steady rate, of say 500,000 gallons per hour, and is flowing, at the same rate, from 6 P. M. to midnight, and from 6 A. M. to

noon, steadily back into the river. If, therefore, it be required to represent the rate-of-flow of the river, that is, the quantity of water passing per hour, or per second, it will be necessary to employ a new diagram, such as that shown in Fig. 2. Here distances above the line 0 0, corre-

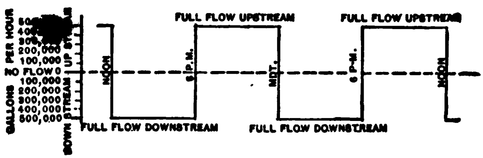


FIG. 2.—CURVE OF TIDAL FLOW.

spond to flood tide, or flow up stream, and distances below the line, correspond similarly to ebb tide, or flow down stream. Thus, between noon and 6 P. M., 500,000 gallons per hour, or nearly 140 gallons per second, flow steadily down stream toward the mouth, while from 6 P.M. to 12 midnight, there is the same flow up stream.

If the above diagrams represented the actual condition of affairs, high water and low water could only exist for an infinitesimally small interval of time, whereas, we know that slack water has an appreciable duration, and that the rate of rising or falling is not uniform, but is greatest about

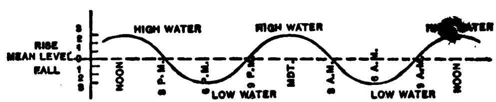


FIG. 3.—TIDAL LEVEL OF RIVER.

mean tide. This is represented for the ideal case of a 12-hour period and a uniform tide, in Fig. 3, and the flow diagram in Fig. 4, corresponding to Fig. 3, shows that the rate-of-flow, instead of changing direction abruptly, does so gradually, so that instead of the rectangular wave of Fig. 2, we have a smooth wave.

Figs. 2 and 4 may also be taken to represent alternating-electric current flow as well as alternating tidal flow, except that a period would then correspond to but a fraction of a second, instead of approximately 12 hours, and the rate-of-flow

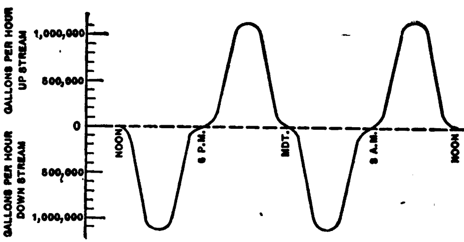


FIG. 4.—CURVE OF TIDAL FLOW.

would be measured or marked off, not in *gallons*-per-hour, but in units of electrical flow called *coulombs*-per-second.

Fig. 5 is a reproduction of Fig. 2, except that the period is 1-100th of a second, corresponding to an electrical frequency of

100 cycles, or 200 alternations per second; while the flow is alternately, say 50 coulombs of electricity per second in one direction, and then 50 coulombs-per-second in the opposite direction.

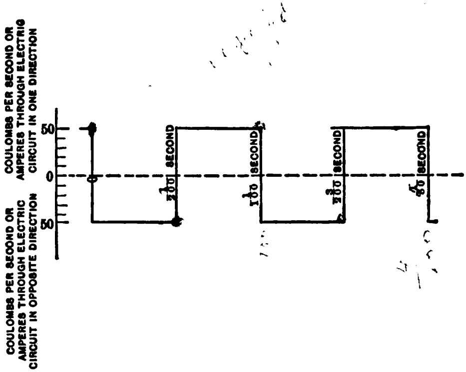


FIG. 5.—CURVE OF ALTERNATING-CURRENT FLOW.

A coulomb-per-second, considered as a rate of flow, is called an *ampere*. Instead, therefore, of using the phrase coulomb-per-second, we may use the word ampere.

The current strength, or flow, represented by Fig. 5, is alternately 50 amperes in one direction and 50 amperes in the opposite direction throughout all parts of the conducting circuit.

In an alternating-current circuit, that is, in a complete conducting path through which alternating-electric currents may flow, the current strength, at any instant, as expressed in amperes, is the same at all parts of the circuit, so that if the current strength be 50 amperes in one direction, it will, as a rule, at that moment, be 50 amperes in that direction throughout the circuit, and, when the reversal takes place, it will practically do so coincidently throughout the circuit, and the current strength becomes, as is seen in Fig. 5, 50 amperes in the opposite direction in all parts of the circuit.

Fig. 6 is practically a reproduction of Fig. 4, and represents an alternating current with a frequency of 50 cycles, or 100

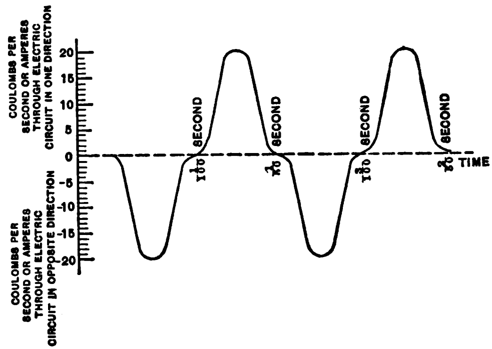


FIG. 6.—CURVE OF ALTERNATING-CURRENT FLOW.

alternations per second, and a maximum strength of 20 amperes in each alternation. The condition of things represented in Fig. 6, is a much closer approximation to the actual state of most commercial alternating-current circuits than that represented in Fig. 4, since, in fact, the electric cur-

rent can never change instantaneously from a full positive to a full negative strength, or vice-versa, but usually follows some smooth curve.

For convenience, we have compared the flow of water through a river channel with the flow of electricity through a conducting channel or circuit. We should, however, carefully avoid falling into the error of carrying this analogy too far, since electricity is not a fluid, although many of the laws of its passage and flow bear close resemblance to the laws of liquid flow.

Although, at the present time, the exact nature of electricity is far from being known, yet electricity is generally believed to be an effect produced by an active condition in an all-pervading medium called the *ether*. The ether is believed to fill in-

terstellar space and to permeate all bodies, even copper wires, and other equally dense forms of matter. Just what may be the nature of that particular ether activity which constitutes electricity, is not known. It may or may not resemble the particular form of activity in the atmosphere called whirlwind.

The difficulty of obtaining a clear conception of the true nature of electricity arises from our inability to recognize even the existence of the ether by our senses, and our still greater inability to recognize the conditions of its activity. In the case of the atmosphere, we can readily appreciate the phenomena produced by the wind, since the effects are produced on a scale commensurate with the capabilities of our senses. But, were we situated on a distant planet, and had no experience what-

ever of an atmosphere, even though we could perceive, through sufficiently powerful glasses, the effects of storms on the earth, we would, probably, have as great difficulty in understanding the nature of phenomena produced by wind power, as we now have in understanding the nature of electrical phenomena, as possible effects of ether disturbance.

The researches of the eighteenth century gave rise to the belief that electricity was a subtle fluid to which the name of electric fluid was given. The researches of the nineteenth century have promoted the belief that this fluid is no other than the all-pervading ether which serves to convey over apparently empty spaces heat, light, gravitational force, and magnetism. Certain characters of disturbance in this medium produce phenomena which we recognize as electrical, while other dis-

turbances of a distinct but interconnected character with the preceding, give rise to phenomena which we recognize as magnetic.

CHAPTER II.

ALTERNATING ELECTROMOTIVE FORCES AND CURRENTS.

In all commercial applications of electricity the following combinations of parts are needed; namely,

(1) A device called a *source*, where the electric current originates.

(2) Devices called *translating* or *receptive devices*.

(3) *Conducting paths* connecting the translating devices with the electric source.

In all cases, after an electric current has left its source and produced some peculiar effect in a receptive device, placed in its path or circuit, means must be provided

whereby the current may flow back again to the source. In other words, the electricity invariably leaves the source, passes through various conducting paths, produces effects in the translating devices, and flows back to the source from which it came. For this reason, the conducting path is usually called a *circuit*, although of course it is not necessary that the path through which the electricity flows should be a circular path.

Electric sources do not primarily produce electricity, but a particular variety of force called *electromotive force*, (generally abbreviated E. M. F.). This force, in its turn, tends to produce electric current. In point of fact, an electric source, although it will always produce electromotive force in a conducting circuit connected to it, yet will not produce an elec-

tric current in such circuit, unless the circuit be *closed* or *completed.*

Electromotive forces are either *continuous* or *alternating.* A continuous electromotive force is *unidirectional; i. e.*, has continuously the same direction, and produces, when it acts upon a closed circuit, what is called a *continuous* electric current. An alternating electromotive force is one which alternates in direction, and, when applied to an electric circuit, produces an *alternating* electric current; that is, an electric current, the direction of which periodically changes with the change in the direction of the E. M. F.

A voltaic cell is an example of an electric source which produces a continuous electromotive force. A common and convenient form of voltaic cell, much employed on telegraph lines, is called the

Daniell Gravity Cell. Such a cell is shown in Fig. 7. It consists of a plate of copper *C*, and a plate of zinc *Zn*, immersed respectively in aqueous solutions of copper

FIG. 7.—GRAVITY CELL.

sulphate and zinc sulphate. A solution of zinc sulphate will float on a solution of copper sulphate, being lighter than it, and since this fact is utilized to keep the liquids separated, the form of cell in which the solutions are thus separated, is called the gravity cell.

The current produced is conventionally assumed to leave the cell at its *positive* or copper pole, and to return to it, after having passed through the conducting circuit, and its receptive device, at its *negative* or zinc pole. When the terminals of the cell

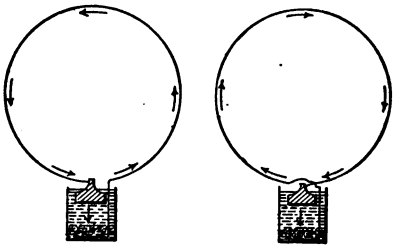


FIG. 8.—ILLUSTRATING REVERSAL IN DIRECTION OF CURRENT THROUGH AN ELECTRIC CIRCUIT ON THE REVERSAL OF ITS ELECTROMOTIVE FORCE.

are connected to a circuit, a current will flow through the external circuit from the copper pole to the zinc pole, as shown in Fig. 8. But if the terminals of the cell be reversed, the direction of the flow through the conductor will be reversed,

and, if these reversals are made five times per second, then there will be five alternations of electromotive force and current in the circuit per second. The alternating currents employed in practice, are not, however, obtained in this way, but from special machines called *alternators*.

In its action on an electric circuit, a continuous electromotive force resembles the action of a *watermotive force*, or pressure in a reservoir, which forces a steady stream of water through an outflow pipe. An alternating electromotive force resembles in its action the action of an *alternating watermotive force*, or pump, alternately pumping water into and out of a reservoir through a pipe. Water engines, operated by water pressure alternately exerted on opposite sides of a piston, after the general manner of the action of a steam

engine, afford an instance of such an alternating watermotive force.

When a continuous electromotive force is applied to a conducting circuit, such, for example, as a mile of insulated copper wire, the current which passes through the circuit will be twice as great as it would be, if the same E. M. F. were applied to a circuit of the same length of such wire, but of only half the weight or area of cross-section; for, the thicker wire conducts electricity twice as well as the thinner wire; or, in other words, offers but one-half the resistance.

Electrical resistance is usually expressed in units called *ohms*. The ohm is the resistance offered by a given length of conductor of definite cross-section. When the resistance of any circuit is

known in ohms, the current, produced by applying to this circuit a known E. M. F., can be calculated in amperes, by a rule called *Ohm's law*, from the name of its discoverer, Dr. Ohm, of Berlin.

Ohm's law is usually expressed as follows:

The current in any conducting circuit, expressed in amperes, is equal to the total electromotive force in the circuit, expressed in volts, divided by the resistance of the circuit, expressed in ohms.

In other words, the amperes in any circuit are equal to the volts divided by the ohms. Thus, the electromotive force usually supplied to incandescent electric lamps is about 110 volts, and since the resistance of the carbon filament in a sixteen-candle power lamp, when lighted, is, say 220 ohms, the current strength,

which will pass through such a lamp, is 110 volts ÷ 220 ohms = 1-2 ampere.

If the electric resistance of any insulated wire be measured in ohms, the value will be found to be the same, whether the wire be straight or bent; *i.e.*, whether the wire be stretched in a straight line, or be wrapped in a close coil; for, when a continuous current is once established in a wire or conductor, bends or turns in the direction of the conductor do not offer any additional resistance to the flow of the current. When, however, an alternating electromotive force is applied to a wire, the strength of the current established in the circuit is considerably influenced by the disposition of the wire, that is, whether it forms a single loop, or whether it forms a coil of many turns. In the latter case, the current which

flows is much smaller than that obtained by dividing the E. M. F. in volts, by the resistance of the coil in ohms. In other words, a different law appears to govern the current strength in an alternating-current circuit than that which governs it in a continuous-current circuit. A circuit containing coils of wire, acts toward an alternating E. M. F. as if it possessed a higher resistance than when traversed by a steady current. In other words, the passage of an alternating current through a coil of wire is opposed by an influence which tends to choke or diminish the current. This influence is called the *reactance* of the coil. The nature of reactance will be understood from a consideration of the following principles: When an electric current is sent through a conductor, the conductor thereby acquires all the properties of a magnet, as was first

shown by Oersted, in 1819. Could we see the actual state of things which exists in the neighborhood of an active conductor, it is believed that we would be able to see around the conductor, a streaming motion in concentric circular paths, of the highly tenuous, all-pervading medium, called the ether.

The ether streaming motion is called *magnetism*. It is most energetic in the immediate neighborhood of the conductor, gradually becoming weaker at greater distances from it. Moreover, the direction of the streaming depends upon the direction of the current in the conductor. For example, if, as in Fig. 9, the current passes downward through the plane of the paper, that is, from the observer, the direction of the streamings will be the same as the direction of the hands of a watch.

These ether streamings occur in the space around every magnet, as well as in the space around an active conductor, and constitute what is called a *magnetic field.*

If the conductor be given the form of a

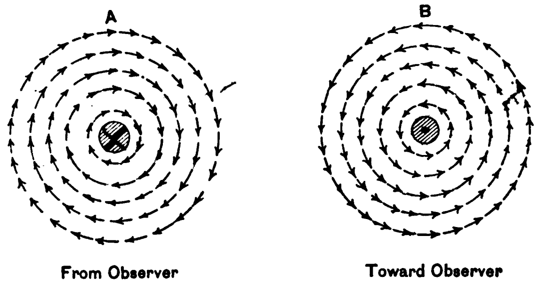


FIG. 9.—DIAGRAMS OF FLUX PATHS ROUND A WIRE CARRYING A CURRENT FROM AND TOWARD OBSERVER.

loop and the ends of the loop be connected with an electric source, so that an electric current flows through the circuit so formed, then the ether streamings, or the magnetic flux surrounding the wire, will be so directed that all the flux will enter

the loop at one side and leave it at the opposite side. The only effect produced by changing the direction of the current, will be to change the direction in which the flux passes through, or threads the loop. If, for example, with one direction of current flowing through the conducting loop, the magnetic flux enters the loop from above and passes out below, then reversing by the direction of the electric current, the flux would enter the loop from below and pass out from above.

The effect of impressing any E. M. F. on a conducting loop is, therefore, to cause magnetic flux to thread or pass through the loop. Conversely, the effect of causing magnetic flux to pass through a loop is to produce an E. M. F. in the loop. This E. M . F . continues only while the flux passing through the loop is changing in

amount; or, in other words, while it is increasing or decreasing. An E. M. F. set up in this manner in a conducting loop is called an *induced* E. M. F. The direction of the induced E. M. F. is opposite to the direction of the E. M. F. which was required to produce the flux that caused it. In order to distinguish the E. M. F. producing the flux, from the E. M. F. produced by the flux, the former is called the *impressed* E. M. F. In other words, the passage of magnetic flux through a conducting loop, consequent upon the application of an E. M. F. to such loop, will tend to set up in the loop an E. M. F. oppositely directed to that of the impressed E. M. F. The induced E. M. F. is, consequently, called a *counter electromotive force;* and, since it is produced by induction, it is sometimes called the *counter electromotive force of self-induction.*

The intensity of the counter E. M. F. so set up, depends upon the rate of change in the amount of flux passing through the loop at any moment, and not on the total amount of flux. Consequently, when the direction of current is reversed, as in an alternating-current circuit, the direction of the flux is reversed, and a rapid change occurs in the rate at which the flux is passing through the loop.

The effect, therefore, of applying an alternating E. M. F. to a coil of wire is to produce, by induction, a resistance to current flow greater than the resistance to steady currents. This total apparent resistance, which is generally called *impedance*, arises from the fact that the rapid filling and emptying of the coils with magnetic flux, set up an E. M. F. counter or opposed to the E. M. F. driving the flux

through the coils, and, therefore, impedes the flow of current through the coils. The effect of the impedance is to prevent the immediate application of Ohm's law to an alternating-current circuit.

The resistance of 100 feet of insulated copper wire of the size represented in Fig. 10, and which is known commercially as

FIG. 10.—No. 13, A. W. G. WIRE, FULL SIZE.

No. 13, American Wire Gauge, contracted *A. W. G.* is approximately 1-5th of an ohm. If a continuous E. M. F. of one volt be maintained between the ends of this wire, the current strength through the wire, whether straight or wound into a coil, would, by Ohm's law, be five amperes (1 volt ÷ 1-5th ohm = 5 amperes). But if an alternating E. M. F. of one volt, reversing

250 times a second, and, therefore, having a frequency of 250 reversals, or 125 cycles per second, be connected to the ends of the wire, the current strength through the wire, if the wire be wound into a coil of many turns, will be considerably reduced, say to 2 amperes, and the impedance, or *apparent* resistance of the wire, will be 1-2 ohm, instead of 1-5th ohm.

The impedance increases both with the frequency and with the number of turns in the coil. But, as we have already seen, a counter E. M. F. is produced in a coil by a change of flux passing through the coil. The effect of introducing iron into the path of the magnetic flux, is to increase the amount of flux which passes, owing to the fact that iron conducts magnetic flux much better than air. If, then, a coil of wire be wound on a suitable core

of iron, the flux passing through the coil, at each reversal of current, will be greatly increased, and, consequently, the reactance of the coil will be increased, or the coil will possess a greater impedance and a more marked choking effect, when the core is present, than when it is absent.

It might be supposed that alternating-electric currents possess a marked disadvantage over continuous currents from the fact that the introduction of coils of wire into their circuit necessarily tends to impede or choke the current flow; for, as is well known, nearly all electric apparatus contain coils of wire, as, for example, electromagnets. But this very fact, so far from being an unmitigated detriment, is often employed to great advantage, where the amount of current which can flow through a circuit is automatically choked

or throttled by the impedance of coils of insulated wire. In fact the capability of introducing reactance, practically without resistance, into an alternating current circuit, is one of the principal advantages of alternating currents.

It is true that an electric current, whether continuous or alternating, can be readily diminished in strength by the introduction into the circuit of mere resistance, called *ohmic* resistance, because its resistance depends only on the nature of the wire, its length and area of cross-section, and is independant of the disposition of the wire, or its coiling. But, in the case of an alternating current, the counter E. M. F. prevents a portion of the electromotive force from acting and, therefore, decreases the amount of electrical work done, or energy usefully ex-

pended, while with the continuous current, although the current is reduced, yet the entire E. M. F. is acting and, consequently, there is a greater expenditure of power.

An application of the methods of varying, in certain cases, the strength of current flowing through any circuit, is seen in the solution of a problem, which is often met in practice; namely, to turn down or decrease the brightness of an electric lamp. If this be done, as has frequently been attempted, by introducing into the circuit of the lamp, a mere ohmic resistance; namely, a conductor with but a few turns, then, although the strength of current passing through the lamp is decreased, and power saved in this respect, yet the same current is now passing through the resistance and producing use-

less heat in it. On the contrary, when a reactance, *i. e.,* a coil of many turns, is employed with an alternating current, not only is the current passing through the lamp decreased, but practically no energy is lost in the reactance.

Fig.11 represents a form of device for turning down lights, called a *theatre dimmer*. Here a portion of the circuit containing the lamps is wrapped in the form of a coil *C*, around a laminated ring of soft iron *K;* that is, a ring consisting of plates of soft sheet iron, laid side by side. On the opposite side of the soft iron ring *K*, a copper shield *H*, is placed, capable of being slid over the core *K*, to the right or the left about the axis *D*, by the motion of the hand wheel. With the relative positions occupied by the shield *H*, and the coil *C*, shown in the figure, the

effect of the coil is to throttle, or choke, the current, by its reactance, and thus diminish the intensity of the light given by the lamps. If it be desired to increase the amount of light, that is, to turn the

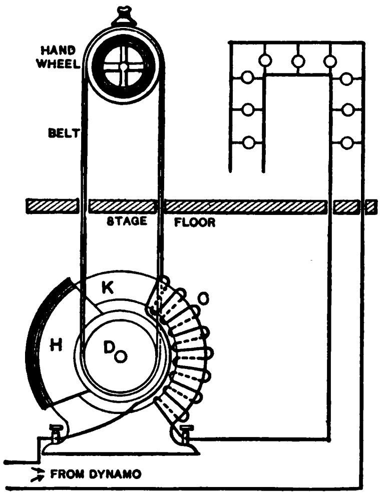


Fig. 11.—Theatre Dimmer, Reactive Coil.

lights up, the metal shield *H*, is moved by the hand wheel toward the reactive

coil *C*, thereby diminishing the reactance of the coil, and thus permitting more cur-

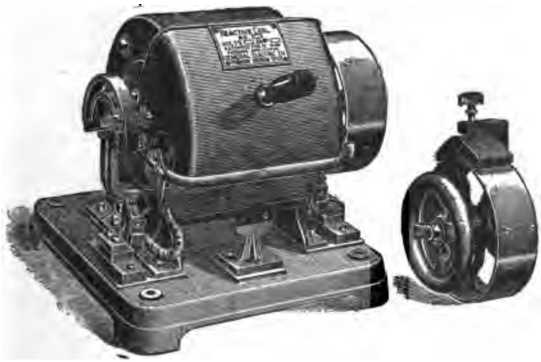


FIG. 12.—THEATRE DIMMER.

rent to flow through the circuit. A motion, therefore, of the metal shield *H*, toward *C*, increases the intensity of the light, while a motion from C, diminishes the intensity. A perspective view of the apparatus is shown in Fig. 12. Fig. 13 shows other forms of theatre dimmer, which operate by the choking effect of react-

ive coils furnished with a movable core consisting of a bundle of soft iron wires.

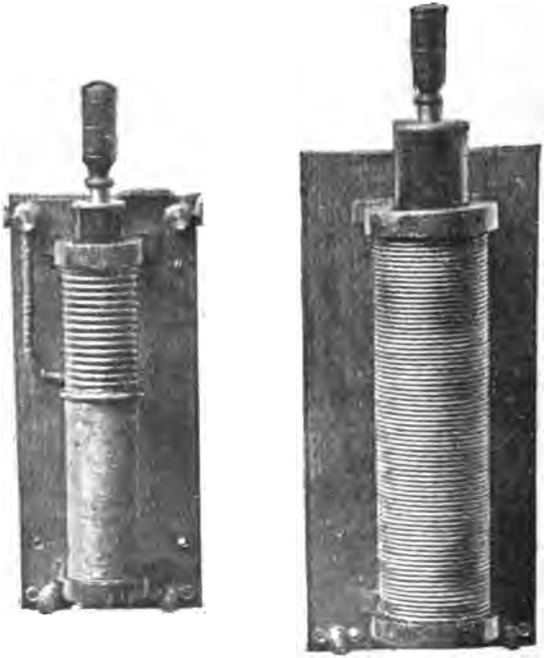


FIG. 13—ALTERNATING CURRENT THEATRE DIMMERS.

Both continuous and alternating currents are capable, when passed through

coils of insulated wire provided with iron cores, of producing electromagnets as shown in Fig. 14. Continuous-electric currents are generally employed for this purpose, since the magnetizing coils do not then act to throttle the current. When alternating-electric currents are passed through the coils of an electromag-

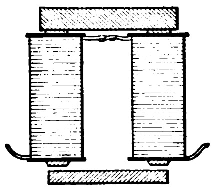


FIG. 14.—FORM OF ELECTROMAGNET.

net, although such a magnet does not possess as powerful attraction for its armature, as when excited by continuous currents, yet it often possesses the advantage of exerting a more nearly uniform pull over a greater distance. Of course, in alternating-current electromagnets, the

magnetism is constantly reversing in direction, with each reversal of the current, each pole becoming alternately of north and south polarity.

In electroplating, deposits of gold, silver and other metals are thrown down by the action of an electric current on the conducting surfaces of articles placed in suitable vats. The surfaces which are to receive these deposits, if not already conducting, are made so by various processes, and immersed in solutions of the metals with which they are to be coated. The current employed for this purpose is invariably a continuous current. It is a well-known fact, that an article, which has been placed in a plating bath and has received a coating of deposited metal by the electric current passing through the bath in a certain direction, will have all this

metallic coating gradually dissolved if the current be sent through the bath in the opposite direction; for, in all cases of electro-plating, the metal is only deposited on one of the conducting surfaces connected with the poles; *i.e.*, on the negative, and is dissolved from a plate of metal connected with the opposite or positive pole. Since, in an alternating-current circuit, both the article to be plated and the plating metal become alternately positive and negative, it might be supposed that it would be impossible to produce any permanent plating whatever by such a current, and, although this is true to the extent of preventing plating from being carried out practically by such methods, nevertheless, permanent electro-plating effects can be produced by alternating currents, when certain relations exist between the size of the article to be

plated and the strength of the current passing.

So far as the heating effects of the electric current are concerned, alternating currents produce the same amount of heat that continuous currents do. For example, if an incandescent lamp be connected to a continuous-current circuit of 110 volts pressure, and, subsequently, to an alternating-current circuit of 110 volts pressure, the amount of light and heat, which the lamp will give off, will be the same in both cases.

A marked difference exists between the physiological effects of an alternating and a continuous current. When a continuous current is sent through the human body, chemical and physiological effects are produced, entirely distinct from those which

attend the passage of an alternating current under similar circumstances. When passing through the vital organs of the body, any electric current, whether continuous or alternating, may, if sufficiently powerful, cause death. Alternating currents, however, at commercial frequencies and pressures, are much more apt to produce fatal effects on the human body than continuous currents. In New York State, alternating electric currents are used for the execution of criminals, and, when properly employed, produce absolute, instantaneous, and painless death.

The experiments of Tesla and others have shown that at frequencies and pressures far higher than those employed for ordinary commercial purposes, the physiological effects of alternating currents become less severe, and that at extraordina-

rily high frequencies, enormous pressures may be handled with impunity.

It should be remembered, however, that the physiological effects produced by a current depend largely on the resistance offered to its passage through the body by the skin. For example, when an alternating current is sent through the human body, by immersing the hands in saline solutions connected with an alternating-current circuit, a pressure even as low as five volts will usually produce very painful sensations. Care, therefore, should always be taken in handling the wires from any high-pressure electric source particularly if that source be one supplying alternating currents.

In an alternating-current circuit, both the strength and the direction of the E. M. F. and current are periodically varying,

being at certain times at greatest strength and at others entirely absent. It is evident that it would not be correct to estimate the value of an E. M. F. or a current at either its greatest or its least value; nor is it usual to take the average value. Instead of this a certain value, both of the E.M.F. and the current, called respectively the *effective E. M. F.* and the *effective current strength*, are taken as estimated from their equivalent heating effects. Thus, an alternating-current pressure of 100 volts is one which, as already mentioned, will produce in an incandescent lamp the same heating and, therefore, the same degree of illumination as 100 volts of continuous-current pressure. In the same way an alternating-electric current, whose values at different successive instants in any cycle would be considerably above or below one ampere, would be regarded as having an

effective current strength of one ampere, if it produced the same heating effect in a coil of wire as a continuous electric current of one ampere.

This method of estimating the values of alternating E. M.F.'s and currents is universally employed, and entirely dispenses with the necessity for a determination of the shapes of the alternating-current waves, just as any method of measuring tides, which depended upon a measurement of the total quantity of water moved up stream during each tide, would dispense with the necessity for determining the exact shape of the tidal wave.

CHAPTER III.

UNIPHASE ALTERNATORS.

During the last few decades there has been witnessed a marvelous development in the commercial applications of electricity. Perhaps the most striking feature in this development is to be found in the strength of the electrical currents employed to day, as compared with the strength of those which were commercially possible only a few years ago. Electricity has commercially entered fields, which, but a comparatively short time ago, would have been closed to it by reason of the expense attending its production.

This development has not been rendered possible so much by improvements

in the apparatus operated by electricity, as it has been in the improved methods for producing electricity more cheaply. For example, to take the field of electric lighting, in which the most marked developments were first manifested; although the arc lights of to-day are, in their way, marvels of mechanical and electrical ingenuity, yet, in point of fact, they do not differ radically, in their general construction, from those produced fifty years ago. Why then did not these early arc lamps enter into more general use ? Surely not on account of any lack of appreciation on the part of the general public, of the advantages possessed by the voltaic arc as an artificial illuminant, but because, in those early days, the only practical means for producing electrical currents was an expensive and inconvenient source of electric supply; namely, the primary, or

voltaic battery. That which rendered electric lighting, as well as most of the many other commercial developments of electricity which followed in its wake, commercially possible was the production of a means for cheaply producing electricity, on a large scale; viz the invention of the generator known as the dynamo-electric machine.

It is a well-recognized principle, in the physical world, that in order to perform work of any kind, whether mechanical, chemical or electrical, energy must be expended. Consequently, the production of a definite amount of electrical energy requires the expenditure of a definite amount of work.

A machine is a device for transforming one kind of work into another. Thus a steam engine and boiler form a machine

for transforming, into mechanical work, the work of heat, liberated by the burning of coal. Despite the fact that the steam engine has been repeatedly improved, since the early days of Watt, in 1765, yet in the best forms of triple-expansion engines, as produced to-day, the work delivered by the engine amounts to but about sixteen per cent. of the work delivered by the coal; so that, although the steam engine can transform the work of heat into mechanical motion, it throws away, during the process of transformation, five parts out of every six. Contrasting with this the modern dynamo machine, the latter will be found a far more efficient agent for the transformation of energy; for, even in small sizes, of say one H.P., it is capable of delivering, as electrical work, 75 per cent. or about three parts out of every four, of the mechanical work ex-

pended in driving it, while in large sizes, of, say thousands of H.P. it is capable of delivering as electrical energy 98 per cent. of the mechanical energy it receives.

Although in practice dynamo-electric machines are generally driven by steam engines, yet their economy over other electrical sources is so great as to warrant this use, despite the low efficiency of the steam engines. Since the expense of maintaining steam power decreases markedly with the size of the steam plant, and since, as we have seen, the capability of the dynamo increases with its size, it is generally found more expedient, in practice, to generate electrical currents in large quantities at a few points called *central stations*, distributing the electrical power to consumers by means of suitable distribution circuits, than it is to have

as many individual plants as there are consumers of the electric current. This is especially the case where dynamos are driven by cheap water power.

A visit to any central station, where electricity is being generated on a commercial scale, will, on even a casual observation, enable one to readily divide the machinery into two distinct classes; namely, the *driving machinery* and the *driven machinery*. The driving machinery will consist either of steam engines or of water wheels. The driven machinery will consist of various forms of dynamos. The driving and driven machinery are connected together, either by means of *belting* or *ropes*, or are rigidly coupled together on the same shaft.

At first sight it may seem that different types of dynamo machines differ radically

in their detailed construction. A closer inspection, however, will show that such differences are apparent rather than real; for it will then be seen that all have certain parts in common; namely, the part called the *armature*, in which the electric current is generated, and the part called the *field magnet* in which the magnetic field of the machine is generated.

Attention has already been called, in the second chapter, to the fact that when loops of wire are filled and emptied with magnetic flux, *electromotive forces* are generated in the wire. The *dynamo-electric machines* that we see operating in a central station, are devices for filling and emptying, with magnetic flux, conducting loops that are placed on the armature of the machine. In order to do this, either the armature or the field is rotated. Usually

it is the armature that is rotated, since the armature is generally the lighter part.

The E. M. F. generated in such conducting loops, reverses its direction twice during each rotation of the armature in a *bipolar field; i. e.*, a field having one north and one south pole. All dynamo-electric machines are capable of ready division into two sharply marked classes; namely, those in which alternating E. M. F.'s are delivered to the consumption circuits, that is, the circuits external to the machine, producing in them alternating-electric currents, and those in which such E. M. F.'s are commuted, or given the same direction, by means of devices called *commutators*. In other words, all dynamo-electric machines can be divided into *alternating-current dynamos* or *alternators*, and *continuous-current dynamos*.

We have, therefore, a general principle by means of which we can determine whether or not a given machine, which we are examining in a central station, is an alternator, or a continuous-current dynamo, since, in the case of the alternator, the conducting loops of wire on the armature are connected directly to the external circuit, generally by means of brushes resting on simple *collector rings*, while in continuous-current dynamos, the brushes, instead of resting on collector rings, rest on a commutator, which differs from the rings in the fact that it consists of a number of separate conducting bars, insulated from one another.

The preceding principle, however, needs some modification, since the requirements of electrical engineering, sometimes, render it advisable to construct dy-

namos so as to render them capable of giving simultaneously both alternating and continuous currents. Various methods are adopted to obtain this result. For example, in some cases a portion of the conducting loops on the armature have the alternating E. M. F.'s generated in them so commuted as to produce a continuous current, while the remaining loops are connected directly to the collector rings, from which the alternating currents are carried off to the consumption circuits, by means of brushes resting on the rings. In such cases, the continuous currents are employed for various purposes, generally for the excitation of the magnetic field through which the armature revolves, which excitation must always be provided by continuous currents.

In all alternators, therefore, continuous

currents must be provided to flow through the field coils. Such continuous currents are either supplied by the machine itself, by commuting a portion of the conducting loops on the armature, or are supplied from a separate source. In other words, all alternators can be divided into two sharply marked classes; namely, those that are *self excited*, that is, supply their own field magnets with continuous currents, and, therefore, must be supplied with a commutator in addition to the collector rings; and those which are *separately excited*, or which derive the continuous currents for the excitation of their field magnet coils from some external source.

Let us now examine some of the dynamos that are commonly met with in central stations in the United States. Take, for example, the dynamo shown in Fig. 15.

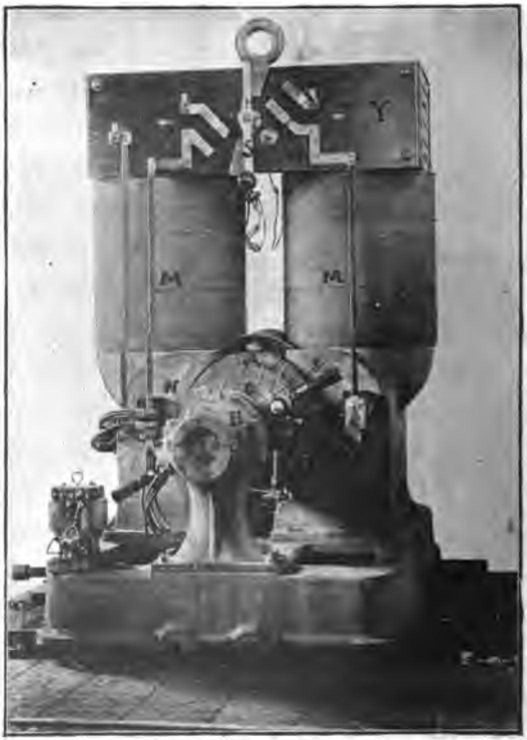


Fig. 15.—Bipolar Continuous-Current Generator.

This is a *bipolar dynamo;* that is to say, its field magnets *M*, *M*, excited by large coils of wire as shown, produce two poles, *N* and *S*, between which the armature *A*,

FIG. 16.—QUADRIPOLAR CONTINUOUS-CURRENT GENERATOR.

is revolved. An inspection of this machine will show that it must belong to the continuous-current type, since the brushes

rest on a commutator *C*, composed of numerous insulated copper bars.

Fig. 16 shows a type of *quadripolar dynamo;* or a dynamo whose field magnet coils, *A*, *B*, *C*, *D*, produce four poles between which the armature revolves. Here again this machine evidently belongs to the continuous-current type, since its brushes, in this case four sets, evidently rest on a commutator, *M*.

Fig. 17 shows a type of separately-excited alternator. Here a small continuous current dynamo D_1, provided with a commutator at *C*, supplies a continuous current through the brushes *B*, to the conductors 1 and 2, to the 12 field magnets *M*, *M*, etc., of the alternator *D*.

In any bipolar generator, whether con-

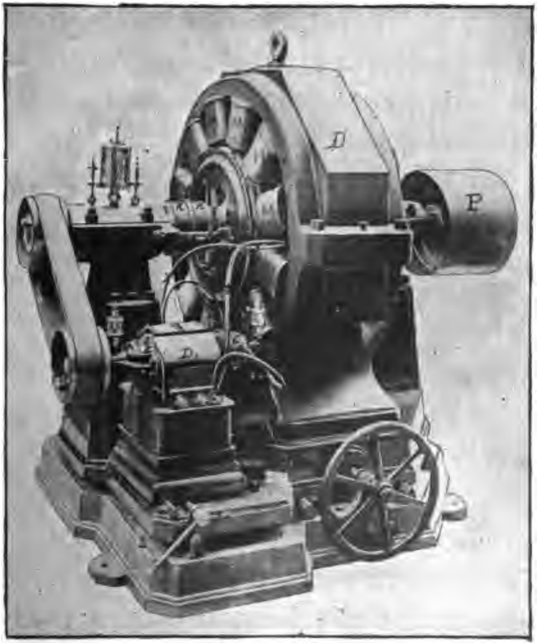


FIG. 17.—SEPARATELY-EXCITED ALTERNATOR.

tinuous or alternating, the two poles are respectively North and South. In a quadripolar machine, such as represented in

Fig. 16, the poles are alternately North and South; and, in general, in generators containing any number of poles, the polarity is alternately North and South, as are the 12 poles in Fig. 17. A moment's thought will show that a *multipolar generator* must, therefore, necessarily contain an even number of poles, since any odd number of poles would bring two poles of the same polarity in juxtaposition. In the alternator shown in this figure, the currents produced by the armature are carried to the external circuit, as alternating currents, by means of brushes resting on the collector rings *R*, *R*, which, according to the principles already explained in Chapter II, become alternately positive and negative during the rotation of the armature past each pole.

Fig. 18 shows another form of separately-

excited alternator. Here the continuous-current generator, instead of being separate from the machine, and connected with it by a belt, as in Fig. 17, is mounted on the

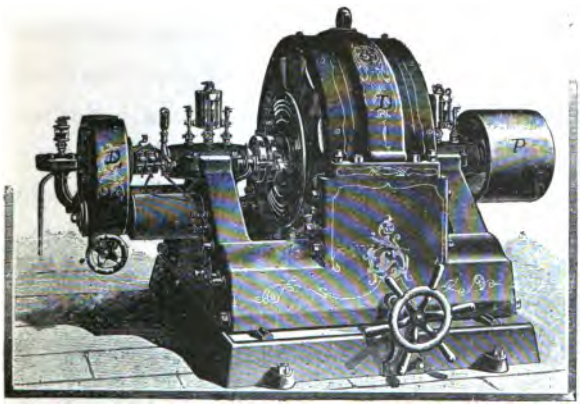


FIG. 18.—SEPARATELY-EXCITED ALTERNATOR.

same shaft as the alternator at D_1, and a continuous current, taken from the commutator and brushes B, is led to the field magnets M, M, of the alternator D. The alternating currents produced in this gen-

erator are carried to the external circuit by means of brushes resting on the collector rings *R*, *R*. The main driving pulley of the machine is shown at *P*.

Heretofore, all the generators we have examined have had but a single circuit of wire on their field magnet coils. Sometimes, however, it is necessary to provide two separate circuits in the exciting coils on the field magnets. Such machines are called *compound-wound*, or *composite machines*. The object of *double-winding* on the field magnets is to maintain automatically the same pressure at the terminals or brushes of the alternator, whether it is supplying a strong or a weak current in its circuit; or, as it is sometimes termed, to *regulate automatically* the pressure under all loads. Fig. 19 represents such a *self-regulating compound-wound alterna-*

tor. Here one of the circuits on the field magnets *M*, *M*, is separately excited by the continuous - current generator D_1. The other circuit on the field magnets is ex-

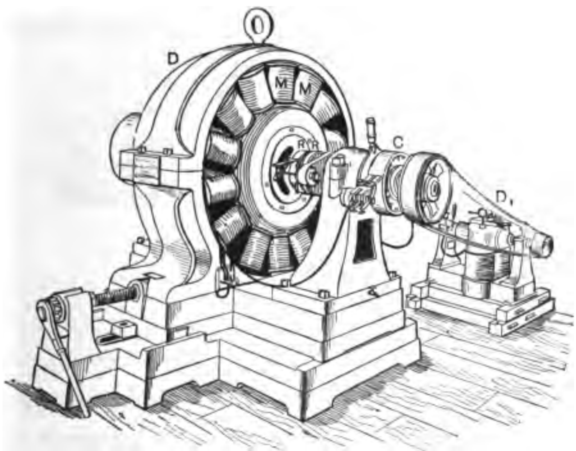


FIG. 19.— COMPOUND - WOUND, SEPARATELY - EXCITED ALTERNATOR.

cited by a portion of the alternating current supplied by the machine, and which is commuted by a commutator *C*. The

alternating current is carried to the external circuit by the rings *R*, *R*.

The electrical connections of such a compound-wound machine are shown in Fig. 20. Here the exciter D_1, sends from

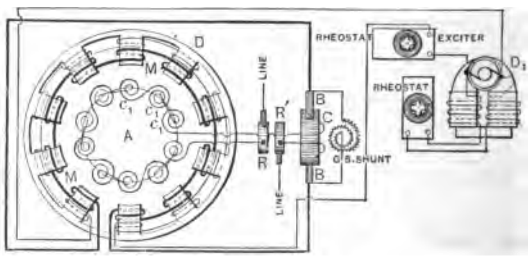


FIG. 20.—DIAGRAM OF CONNECTIONS IN A PARTICULAR COMPOUND-WOUND, SEPARATELY-EXCITED ALTERNATOR.

its brushes a continuous current through an *adjustable resistance*, or regulating device called a *rheostat*, and through a fine wire circuit to the field coils *M*, *M*, which are connected in series. The coils C_1 C_1 C_1 etc., mounted on the revolving armature A, generate alternating currents, which are

connected to the collecting rings *R*, *R*, and to the commutator *C*, as shown; namely, one end is connected directly to the collecting ring *R*, and the other end to the ring R_1, through the commutator *C*. Under these circumstances a certain portion of the current passes around the commutator through the path marked *G. S. shunt*, of German silver wire, passing on as alternating currents to the collector ring, and by means of the brushes to the external circuit or line, as alternating currents, while the remainder, or commuted portion, is fed through the brushes *B*, *B*, to the coarse wire circuit of the field magnets. The effect of this arrangement is, that as the strength of the current supplied to the external circuit increases, the portion of this current supplied to the coarse wire circuit of the field magnets increases, and the field magnets

are thereby strengthened, thus increasing the E. M. F. of the machine by increasing the magnetic flux passing through the coils on the armature.

A self-excited alternator supplies from its own armature, through a commutator, all the current required for the excitation of its field magnets. All alternators may, therefore, be divided into three general classes; namely,

(1) *Separately-excited machines*, in which the currents required for the excitation of the field magnets are obtained from a continuous-current dynamo. Such alternators employ no commutators but only a pair of collector rings.

(2) *Self-excited machines*, which supply all the current required for the excitation of their field magnets, after such current has been rendered continuous by the ac-

tion of a commutator. Such machines, therefore, employ a commutator in addition to collector rings.

(3) *Compound-wound alternators*, which consist practically of a combination of the two preceding types. In other words, the principal excitation of the field magnets is obtained from a separate dynamo, while the additional excitation, needed to maintain a constant pressure at the collector rings under all conditions of load, is obtained from their own armature current through the action of a commutator.

Fig. 21 represents a self-excited alternator with a commutator at *C*, and collector rings at *R*, *R*, for the delivery of alternating currents to the circuit.

In order to familiarize the reader with the varieties of alternators in common use in the United States, two additional ex-

amples of alternating-current machines are given in Figs. 22 and 23. An examina-

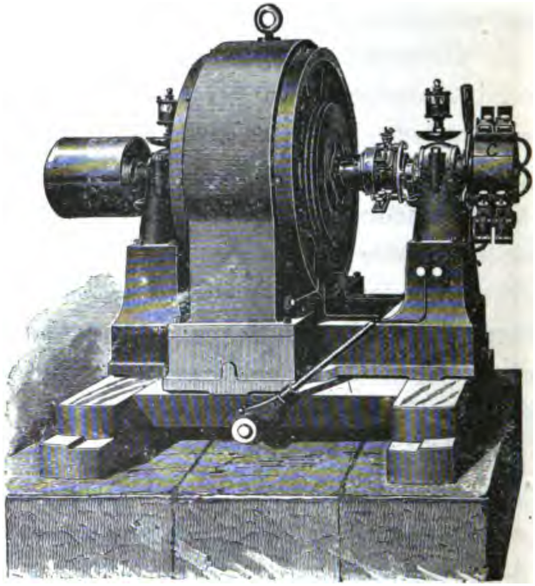


FIG. 21.—SELF-EXCITING ALTERNATOR.

tion of these figures will show that the machines represented belong to the same general type as those already described, the

differences being either in mechanical construction or in the relative arrangement of the parts. For example, Fig. 22

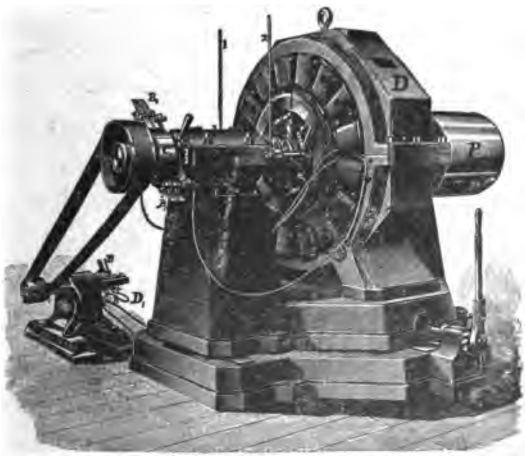


FIG. 22.—2000-LIGHT ALTERNATOR.

shows a separately-excited alternator of 16 poles with collector rings at *R*, *R*, supplying alternating currents, through the leads 1 and 2, to the external circuit. The

separate exciter D_1, supplies commuted or continuous currents to one winding of the field magnets, *M*, *M*, and part of the armature current from the alternator *D*, is supplied through the commutator *C*, to the other winding of the field coils. This machine is, therefore, a *compound-wound, separately-excited alternator*, and agrees in all essential electrical features with the machine shown in Fig.19.

Fig. 23 shows a form of alternator in which only a pair of collector rings is employed. Here the separate exciter, necessary for supplying continuous currents to the field magnets, is not shown, and, as there is no commutator on the machine, it is clearly not compound-wound. This alternator corresponds electrically to the type of machine shown in Fig.17.

Beside the forms of alternators above

described, there are many others. All, however, possess the same fundamental features although these features may dif-

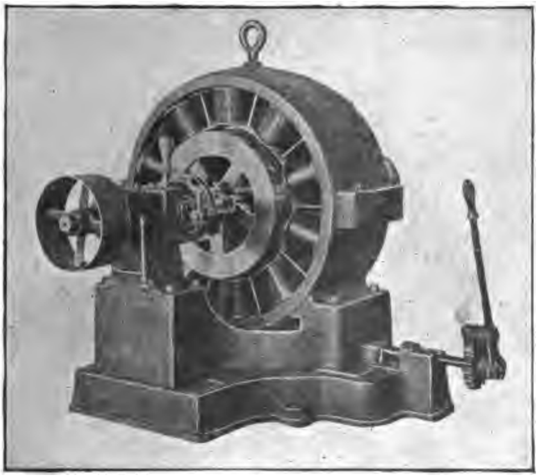


FIG. 23.—1000-LIGHT ALTERNATOR.

fer markedly in their construction details. For example, in some alternators the armature is fixed and the field rotates. In others, both armature and field are fixed,

but a rotating frame is so placed in relation to both as to generate E. M. F.'s in the conducting loops or coils on the armature. Such alternators are called *inductor alternators.*

CHAPTER IV.

POWER.

VISITING an electric central station at the time of full load, that is, when the station is generating its full electric power, it is evident that a great deal of energy is being expended or work being done. The fires under the boilers are working at full draft; the steam engines are working at full steam pressure and speed, and the dynamos, if belt-driven, are receiving practically all the energy liberated by the engines through their tightened connecting belts. Evidently, therefore, the *driving machinery* is transmitting an enormous amount of power to the *driven machinery*. Indeed, not infrequently several thousand horse-power are

thus delivered in large central stations, from the steam engines to the dynamos. But there is no immediate evidence to the eye, as to what becomes of all this power. Our everyday experience would lead us to expect some more evident effect produced by the expenditure of so much power. Were the engines suitably mounted on wheels and placed on a railroad track, the same amount of power applied to driving wheels would be sufficient to carry the entire plant along the road at a considerable speed. In the central station, however, the energy is transformed into electrical energy which is being silently carried away by the conductors. These silent conductors, however, are capable of delivering up the energy given to them at various points along their circuit, and if all this energy were employed to drive electric motors, the total work

which could be performed by such motors, provided no loss occurred in transmission, would of course be equal to that developed by the steam engines.

It is evident, then, that a circuit conveying an electric current, may, in its turn, be regarded as a source of driving power by which the motors are driven. But in the case of the steam engine, there is an evident connection between the driving and the driven dynamo; namely, the belting or shafting. There must also be some connection between the dynamo as a driving and the motor as the driven machine. Here the connection, though far less evident, consists in the conducting circuit connecting the dynamo and motor; or, in other words, the conducting circuit, and its electric activity, take the place of the driving belt.

Suppose a water motor is operated in a city by the flow of water through a pipe, connected with a reservoir on an adjoining hill. Here, clearly, the source of energy received by the motor is the moving or falling water. This energy, in its turn, was received from a pump which raised the water into the reservoir, from, possibly, a river or lake at a lower level. Moreover, the amount of energy received by the motor is perfectly definite, since each pound of water, falling from a height of one foot, conveys an amount of *work* called a *foot-pound*, so that, if the reservoir contains a million pounds of water, and the difference of level between the reservoir and the motor is 100 feet, then the total source of work upon which the motor can draw, is $100 \times 1,000,000$ or 100,000,000 foot-pounds.

This stock of power in the reservoir

might be expended by the water-motor in a day, or in an hour, according to the rate at which the motor works, and, therefore, permits the water to flow from the reservoir. In other words, the ability of the unreplenished reservoir to keep the motor running for a given time, depends upon what is called the *activity* of the motor, or the rate at which it is doing work. This activity is usually expressed in *foot-pounds per second*, or in *foot pounds per minute.*

The commercial unit of activity is the *horse-power*, or 550 foot-pounds per second. If, then, the motor be a one horse-power motor, and, for simplicity of calculation, be supposed to be a perfect machine; *i.e.*, to waste no power in friction, then the flow of water through the pipe will be 5 1-2 pounds per second, and this quantity of water falling one hundred feet

in one second will produce an activity of 5 1-2 $\times$ 100 = 550 foot-pounds per second.

Although electricity is not a liquid like water, yet, since many of the laws which control the flow of water are also applicable to the flow of electricity, it is convenient, in considering the manner in which an electric current is able to transmit power to a motor, to regard electricity as though it were a fluid in actual motion. As in the case of water in motion, the amount of activity transmitted can be expressed by the pounds of water flowing per second, multiplied by the difference of level in feet through which it flows, so in the case of an electric current, the activity transmitted can be expressed by the rate-of-flow of electricity in coulombs-per-second, multiplied by the difference of electric pressure

through which it flows, expressed in volts. Moreover, as the activity in the current of moving water is expressed in foot-pounds per second, of which 550 make a horse-power, so the activity in the current of electricity is expressed in *volt-coulombs per second*, or in *watts*, of which 746 make a horse-power. If, therefore, we multiply the rate of electric flow in a circuit, expressed in amperes, by the difference of electrical level or pressure, expressed in volts, the product will be the activity in the electrical circuit expressed in watts, 746 watts being equal to one horse-power.

The activity, or the rate of delivering power from a water reservoir, can be increased either by increasing the difference of level, or by increasing the rate-of-flow; so in an electric current, the activity, or the rate of delivering electric power, can

be increased either by increasing the difference of electrical level in volts, or by increasing the rate of electric flow in amperes.

Steam engines are generally rated in *horse-power* (contracted H.P.); that is to say, a one-horse-power steam engine is capable of doing an amount of work equal to 550 foot-pounds per second. A one-horse-power steam engine, therefore, is capable of lifting a pound weight 550 feet high, or 100 pounds 5 1-2 feet high, in each second of time.

Electric generators are usually rated in watts; but since a watt is so small a unit of activity, being only 1-746th of a horse-power, the *kilowatt* or 1000 watts is the unit generally adopted. Thus, a 1000-watt generator, or a 1 KW. generator, might supply one ampere in its circuit at

a pressure of 1000 volts, between its brushes; or, it might supply 50 amperes at a pressure of twenty volts, or 1000 amperes at a pressure of one volt.

The following examples of electrical activities, required for the operation of apparatus in common use, may prove of interest:

An ordinary incandescent lamp, of 16-candle-power, requires about 50 watts, so that at this rate one electrical horse-power will supply nearly fifteen lamps. The pressures at which such lamps are commonly operated are either about 100 volts or 50 volts. A 100-volt 16-candle-power lamp, will, therefore, usually take a current of approximately 1-2 ampere, since 100 volts × 1-2 ampere = 50 watts; while if the lamp be intended for a fifty-volt circuit, it will require a current of one am-

pere. An incandescent lamp, therefore, requires about 1-15th of a H.P. or about 37 foot-pounds per second to be supplied to it at its terminals in electrical energy.

An arc lamp, of the ordinary 2000 candle-power rating, usually requires some 450 watts for the production of the arc at a pressure of 45 volts. This represents a current strength of 10 amperes, since 45 volts × 10 amperes = 450 watts. An arc lamp, therefore, requires to be supplied with an activity of about 3-5ths of an electrical horse-power; or, in other words, for every arc lamp supplied to a circuit, the engine driving the arc light generator must supply 3-5ths of a horse-power, and something over for losses in transmission.

An electric current of 5000 amperes, supplied from a central station to a net-

work of trolley conductors, in a street railway system, under a pressure of 550 volts at the dynamo brushes, will represent a total activity of $550 \times 5000 = 2,750,000$ watts, or 2750 KW. or 3686 H. P. in electrical energy supplied to conductors.

Although, as we have seen, the rate of work or activity, in a continuous current, is equal to the number of amperes multiplied by the number of volts, yet when we come to apply the same rule to the case of alternating currents, we find that it is only true under certain circumstances.

This is for the reason that, in the continuous-current circuit, the pressure is always acting to drive the current in the direction in which it is already moving, while in an alternating-current circuit it may be at times aiding the current for-

ward, and at times opposing it. Fig. 24 represents the current strength in an alternating-current circuit, and also the E. M. F. of the generator by which that cur-

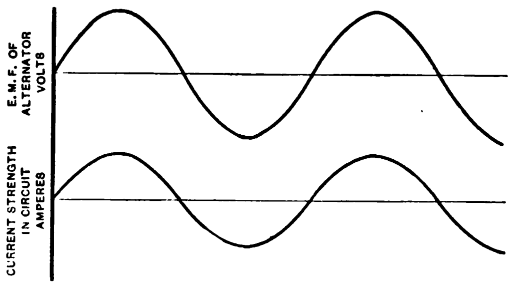


FIG. 24.—WAVES OF ALTERNATING E. M. F. AND CURRENT IN STEP.

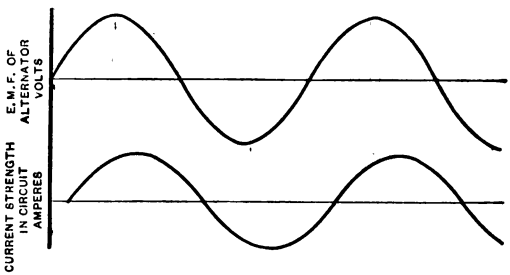


FIG. 25.—WAVES OF ALTERNATING E. M. F. AND CURRENT IN A CIRCUIT, OUT OF STEP.

rent strength is produced. The two sets of waves are seen to be in step, the crests of the E. M. F. waves coinciding with the crest of the current waves. In such a case the product of the effective volts and the effective amperes gives the electric activity, just as in the case of a continuous-current circuit. Fig. 25, however, represents the more usual case in which the pressure or E. M. F. is in advance of the current. It will be observed that at the moment when the pressure has its greatest value, or rises to the crest of its wave, the current strength will not have reached the crest of its wave, the result will be that the pressure will have dropped below the zero line 00, or will have become negative, while the current is still above the zero line, or in the positive direction. In other words, the pressure or E. M. F., instead of aiding the current at this in-

stant, is opposing it. Under these circumstances if we multiply the effective, number of volts by the effective number of amperes, we shall obtain an activity which is greater than that actually produced in the circuit. In other words, the *apparent activity* in watts will be greater than the actual activity in watts, and the discrepancy will depend upon the distances between the crests of the pressure and current waves; *i. e.*, upon the amount of time, in each period, during which the pressure is opposing, instead of driving. The apparent activity, has, therefore, to be multiplied by a quantity called the *power factor*, in order to obtain the real activity. The value of the power factor depends upon the difference of phase. The waves of current and pressure are said to be *in phase*, or *in step*, when their crests and troughs occur simultaneously;

and when the waves of pressure become separated from the waves of current, the two waves are said to differ in phase.

Even in an alternating-current circuit, under certain circumstances, if we take for both of these quantities their effective values, as we have heretofore pointed out, the activity is correctly represented by the product of the E. M. F. by the current. This would be the case in a circuit of incandescent lamps where the circuit is practically free from loops, since, in such a circuit, induction is practically absent. Such a circuit is sometimes called an *inductionless circuit;* but when, as is the case in most practical alternating-current circuits, conducting loops, in the shape of coils of wire, are present, then, as we have already pointed out, the successive filling and emptying of these loops with magnetic flux,

on the rapid periodical increase and decrease in current strength, will set up E. M. F.'s in the wire, counter or opposed to the E. M. F.'s producing such flux, so that the combined effect of the impressed and the counter E. M. F.'s produces what is called a *resultant* E. M. F. which is shifted in position, or differs in amount and phase from the impressed E. M. F. But with this resultant E. M. F. the current is always in step. This resultant E. M. F., multiplied by the current in step with it, gives the true activity of the current. Since, however, the circumstances producing the displacement of the current, in phase, are often complex, it is well to multiply the impressed E. M. F. by the current and introduce a power factor rather than to determine what the resultant E. M. F. in the circuit may be. For example, an incandescent lamp, supplied direct from

mains at an alternating pressure of 100 volts, may take, say half an ampere of current. The activity in the lamp will be $100 \times 1\text{-}2 = 50$ watts, and the power factor is one, or 100 per cent. This is for the reason that there is no reactance in the lamp, and the current waves through its filament are almost exactly in step with the waves of pressure at its terminals. Consequently, the activity of the lamp, and the light it emits, will be the same, whether it be connected to 100 volts alternating or continuous pressure.

If, however, the same alternating-current mains be connected with a coil of many turns, the resistance of which is the same as that of the lamp filament, while the continuous current will be half an ampere as before, the alternating current will be much less, perhaps, only 1-10th

of an ampere, this being due to the reactance of the coil, as already explained. The activity in the continuous current will be 50 watts, but in the alternating current it will not be 100 × 1-10th or 10 watts, but considerably less, because the waves of pressure and current, owing to the reactance of the coil, are out of phase, and the power factor of the coil will be less than say 30 per cent., making an electrical activity in the coil only 10 × 30-100ths = 3 watts.

CHAPTER V.

TRANSFORMERS.

If we leave the central station and follow an alternating-current circuit, erected upon poles, up to the first point where the current is utilized, we will probably see apparatus of the general type represented in Fig. 26, either placed upon a pole, as shown in the figure, or in some convenient location on the side of a building. Such an apparatus is called a *transformer*, and is only employed on alternating-current circuits. It remains now to examine the general construction of alternating-current transformers, and the part they take in the economical distribution of electric currents over extended areas.

If an alternator, at a central station, is

supplying 100 volts at its collector rings, a 100-volt lamp connected at the brushes of such a machine will burn at full incandes-

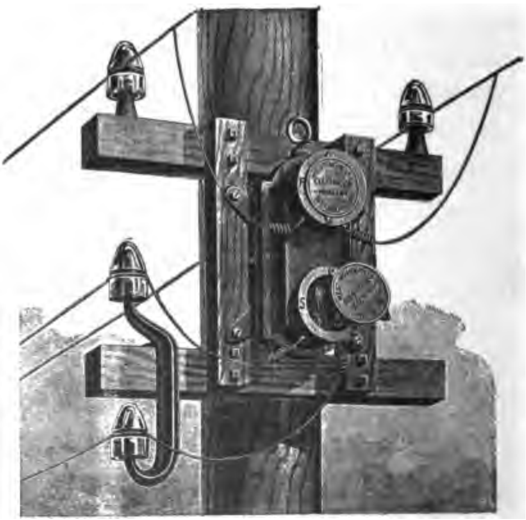


FIG. 26.—ALTERNATING-CURRENT TRANSFORMER WITH DIRECT SERVICE WIRES.

cence or brilliancy. Suppose, now, that this alternator be connected to a pair of wires five miles in length. If the lamps were

connected to the lines as shown in Fig. 27, at distances of 1, 2, 3, 4 and 5 miles respectively, we should find that the brilliancy of the lamps diminished as the distance from the alternator increased; the reason being that the pressure, or voltage, between the lines at the lamp terminals, would decrease as we receded from the

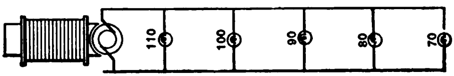


FIG. 27.—DIAGRAM ILLUSTRATING THE FALL OF ELECTRIC PRESSURE OR VOLTAGE ALONG A CIRCUIT.

alternator. This decrease in pressure of electricity flowing from an alternator, through a long conductor, finds its analogue in the decrease of the pressure of water flowing from a reservoir through a long pipe as shown in Fig. 28. If the reservoir supply water through a pipe, and pressure gauges be connected at different distances, say 1, 2, 3, 4 and 5 miles,

as shown, then, when the flow is entirely shut off at the distant end, assuming no leakage through the pipe, the gauges will all show the same pressure; but when the flow is fully established through the pipe, the gauge at the outflow, where the wa-

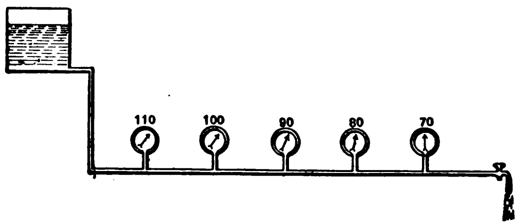


FIG. 28.—DIAGRAM ILLUSTRATING THE FALL OF HYDRAULIC PRESSURE ALONG AN OUTFLOW PIPE.

ter escapes, will, owing to the loss of head, or drop of pressure, arising from the friction of the water in the pipe, show the lowest pressure. The pressure at intermediate distances between the reservoir and the outflow, will be intermediate between the pressure at the reservoir and

the pressure at the outflow. Similarly, in an electric circuit, the resistance offered by the conductors to an electric flow produces a *drop of pressure*, so that under the conditions shown, the most distant lamps will only receive say 70 volts, while the intermediate lamps will receive pressures intermediate between 110 and 70 volts. The fall of pressure depends on the size of the wire and the strength of the current required for each lamp.

An ordinary incandescent lamp of 16-candle-power requires to be supplied, as already stated, with an activity of about 50 watts. Since, in the preceding case, the pressure is assumed to be 100 volts, each lamp would take approximately 1·2 ampere of current (100 volts × 1·2 ampere = 50 watts). If the lamp could be constructed so that it would properly operate when

supplied with say 1-20th of an ampere, or 10 times less current, the current supplied by an alternator to such lamps, under similar conditions, would be 10 times less, and the drop of pressure in the mains would, therefore, be 10 times less, since the drop of pressure in any conductor, expressed in volts, is always equal to the current which it carries in amperes multiplied by its resistance in ohms. But such a 50-watt lamp, taking only 1-20th ampere, would have to be designed for a pressure of 1000 volts (1000 volts × 1-20th ampere = 50 watts). Such lamps can not be conveniently made at the present time, and even if they could be made, 1000 volts is an unsafe alternating-electric pressure to introduce into a building. The only way in which this troublesome drop of pressure can be avoided, without the use of special apparatus, when the best arrangement of

wires has been adopted for the distribution of light, is to decrease one of the factors on which the value of the drop depends; namely, to decrease the resistance of the wires, by increasing their size and weight. In other words, we can always decrease the drop indefinitely, by increasing the size of the conductors indefinitely. But heavy conductors of copper are expensive, and a point is soon reached when the distance, to which electric supply can be carried from a central station to lamps, is commercially impossible.

Happily, however, the use of transformers with alternating currents renders it possible to obtain all the advantages of high-pressure transmission and yet readily to reduce such pressure to 50 or 100 volts within the building it is desired to supply. The corresponding conditions of

hydraulic transmission are represented in Fig. 29 where a long pipe, *PP*, of small cross-section, carries water from a reservoir *R*, at a high pressure and enters the

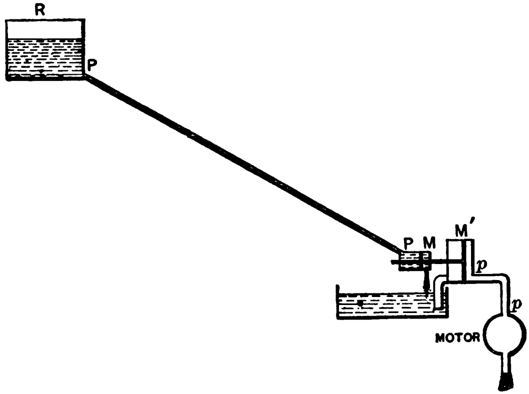


FIG. 29.—DIAGRAM REPRESENTING LONG DISTANCE WATER POWER TRANSMISSION THROUGH SMALL PIPE AT HIGH PRESSURE, WITH TRANSFORMATION TO LARGE PIPE, LOW PRESSURE, LOCAL SYSTEM.

high-pressure cylinder of a pump *M*, connected with a large, low-pressure cylinder of the pump *M*, which drives forward a large quantity of water from a local reser-

voir at a reduced pressure, through a large pipe *p p*, to the water motor in its vicinity. By such an arrangement, therefore, it is possible to transmit water power to a great distance by a small pipe, and yet deliver a large volume of water to a motor which is designed to be operated at a low pressure. In the same way, by the use of alternating currents in connection with transformers, it is possible to obtain all the advantages to be derived from the transmission of high pressure electric currents over small wires, and yet so transform or change the pressure at the point of consumption as to permit the use of incandescent lamps that will only operate economically under low pressures.

It has already been pointed out that the value of the electrical activity transmitted by any circuit when the power factor is

100 per cent. or unity, is equal to the product of the amperes multiplied by the volts, and it is clear that a small electric current, carried at a high pressure, say 10 amperes at 1000 volts, would give the same amount of activity, namely, 10 KW., as would a current of 100 amperes at 100 volts, but would require a much smaller wire.

An *alternating-current transformer* is a device for enabling electric energy to be economically transmitted at high pressure and low current strength, to the point of delivery, and then reducing or transforming this supply to a large current at a correspondingly lower pressure.

Let us inquire into the means whereby a transformer is capable of performing this important function. To do this we will first examine its construction. The

alternating-current transformer consists essentially of two coils of wire, one usually coarse and the other fine, the fine wire coil being of much greater length and having a greater number of turns than the coarse wire. Fig. 30 shows one of the sim-

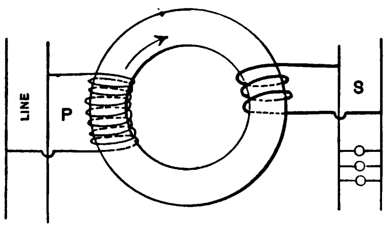


FIG. 30. — SIMPLE FORM OF ALTERNATING-CURRENT TRANSFORMER.

plest forms of transformers. It consists, as shown, of two coils of wire P and S, wound on a core of iron wire. When an alternating current is sent through coil P, called the *primary coil*, it will, by induction, produce an alternating E. M. F., of the same frequency, in the coil S, which

is called the *secondary coil*, and this secondary E. M. F. is employed to send an alternating current through the lamps or other apparatus which are to be operated. In the case supposed, the high-pressure current would be sent through the primary coil *P*, whose terminals are connected to the line, and the low-pressure current would be induced in the secondary coil *S*, whose terminals are connected as shown with the apparatus to be operated.

The alternating-current transformer operates as follows: On the passage of the alternating current through the primary coil *P*, the coil become alternately magnetized in opposite directions; that is to say, its loops become successively filled and emptied with an oscillating magnetic flux. The coil thereby has a counter E. M. F. set up in it, or, in other

words, acts as a choking coil. At the same time, the flux through the iron core successively fills and empties the secondary coil *S*, and thereby induces in it an E. M. F. which will alternate at the same frequency as that in the primary. If the circuit of the secondary coil is *open; i. e.*, disconnected from its apparatus, the presence of this secondary E. M. F. will not affect the reactance or choking effect of the primary coil; but if, on the contrary, the secondary circuit be *closed* through its load of lamps, motors, or other apparatus, the current in the secondary coil will tend to magnetize the core in the opposite direction to that of the primary coil, and so diminish the reactance of the primary winding. The choking effect of the primary coil will, thereby, be reduced as the secondary current and the load increase. In other words, the transformer

becomes *self-regulating*, the choking effects of the primary coil automatically varying so as to permit the right amount of current and power to be received from the high pressure mains, in order adequately to supply the secondary or low pressure consumption circuit.

Let us now examine the pressures which exist in the primary and secondary circuits. If each coil P and S, has the same number of turns, the E. M. F. induced in the secondary will be practically the same as that supplied or impressed upon the terminals of the primary, so that there would be no transformation or change as regards pressure and current. If, however, the secondary coil is made up of but half the number of turns in the primary coil, the flux passing through the iron core only links with half the number

of secondary turns that it links with in the primary coil, and the E. M. F. induced in the secondary will be but half as great as that in the primary. If the primary impressed E. M. F. were 1000 volts effective, that in the secondary circuit would be about 500 volts. Again, if the secondary coil contain say one tenth of the number of turns existing in the primary coil, then its E. M. F. would be correspondingly reduced and would become approximately 100 volts. If in this case the wire forming the secondary coil were maintained of the same diameter as that in the primary coil, the small secondary coil would, for the same electrical activity in each circuit, have to carry ten times the current strength which is supplied to the primary. It would be necessary, therefore, to increase the cross-section of the secondary coil, say ten

times, so that the bulk of the two will, in practice, be approximately the same.

It is evident that if the coil *S*, assumed in the last condition to contain one tenth of the number of turns in the coil *P*, could be connected to the high-pressure terminals, or, in other words, be employed as the primary, that the coil *P*, would have an E. M. F. induced in it, whose value would be ten times as great as that in the mains. Transformers may, therefore, be divided into two sharply-marked classes; namely, *step-down transformers*, where the pressure in the secondary is less than the primary pressure, and *step-up transformers*, where the pressure in the secondary is greater than the primary pressure. In actual practice, transformers are not built in the exact manner shown in the last figure. The primary and secondary coils

may be variously disposed as regards each other, but in all cases they are brought as close together as possible, and are so surrounded by laminated iron as to cause the flux produced by the primary to pass through or become linked with all the turns of the secondary. Since the coils may assume various positions, it is evident that different types of transformers may differ radically in their appearance. They will, however, all possess the same essential features; namely, primary and secondary coils, and a laminated iron core common to both.

Fig. 31 represents a laminated iron core *C*, of sheet iron stampings, having a form resembling that shown in Fig. 32, within the hollow spaces of which are inserted the two coils *P* and *S*, one being the primary coil of say 1000 turns of fine wire, and the

other the secondary coil (for convenience divided into halves) with a total of say 100 turns of coarser wire. Since the primary coil may be connected to mains at say 1000 volts pressure, and is in close juxtaposition to the secondary coil, from which wires are carried into the building to be

FIG. 31.—TRANSFORMER SHOWING INTERNAL CONSTRUCTION.

supplied by the current, it is evident that the insulation of the two coils from each other must be carefully preserved, since, otherwise, the pressure of 1000 volts might be led into the building. In order to ensure a high degree of insulation, the coils are sometimes immersed in an insulating

oil. The transformer coils shown in Fig. 31 at *A*, are placed in the iron vessel shown at *B*, which is then filled with oil.

Another form of *oil-insulated*, *step-down transformer* is shown in Fig. 33. Here the

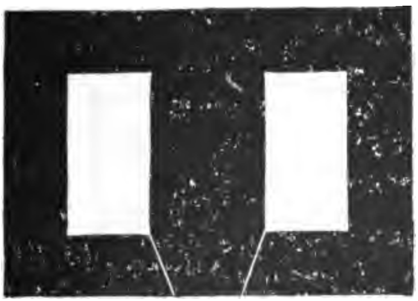


Fig. 32.—Sheet Iron Stamping. For Transformer Shown in Fig. 31.

primary coil has its ends brought out at *p*, *p*, and its secondaries at *s*, *s*, divided, as before, into two halves for convenience. This transformer is enclosed as shown in Fig. 34, in a box filled with oil, the pri-

mary terminals being brought out through the fuse-box at *P* and *P*, and the secondary terminals at *S* and *S*.

In order to prevent the current gener-

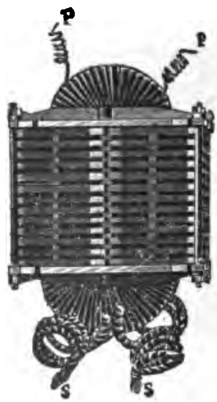


FIG. 33.—100-LIGHT TRANSFORMER WITHOUT BOX.

ated in the secondary circuit from becoming dangerously great, should an accidental short-circuit occur in the wires of the

building supplied, a device called a *fuse-block* is employed with transformers. This device consists of an iron box containing lead fuse wires which are inserted

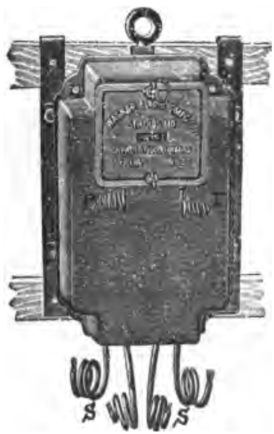


FIG. 34.—100-LIGHT STANDARD TRANSFORMER.

in the primary circuit, so that the current from the high-pressure mains, in order to reach the primary coil, has to pass through these fuse wires. The fuse wires

are composed of a lead alloy of such size that they carry safely the normal working current of the transformer, but, on an undue excess of current, become so heated as to melt, and open the circuit, thus automatically disconnecting the transformer from the mains. The porce-

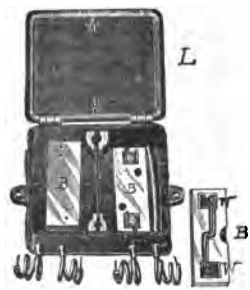


FIG. 35.—FUSE-BOX AND FUSES.

lain or earthenware fuse-block is shown in Fig. 35 at *B*, with a fuse wire *WW*, laid across it, having its ends clamped under connection screws. The box is

provided with the lid *L*, so that when the fuses have been melted or "*blown*" new wires can be readily inserted.

Another form of *transformer fuse-box* is

FIG. 36.—DETAILS OF TRANSFORMER FUSE-BOX.

shown in Fig. 36, detached from its transformer case. Here, two unglazed porcelain handles *H*, *H*, are inserted by hand into two separate porcelain apartments in an iron box. Within these compartments

are brass contact pieces, only one of which S_1, is visible in the figure, so arranged that when the handle *H*, *H*, is pressed home into the compartment, connection is maintained between them through the fuse wires, *W*, *W*, clamped between binding posts *T*, *T*, and connected with flexible plugs *S*, *S*, which fit into the receptacles S_1. The lid *L*, is provided for closing the box. The advantage of this particular form is that when the handles are pushed in, thus connecting the transformer with the high-pressure mains *P*, *P*, the sudden or explosive fusing of the wire cannot injure the operator, whose hand is protected by the back of the handle *H*.

Fuse wires are also inserted in the secondary circuits of the transformer, sometimes in the transformer itself as at *S*, in Fig. 26, and, sometimes, in separate fuse-boxes within the building.

We have seen in Figs. 31, 33 and 34, that the secondary coils are divided into two separate halves. The advantage of this method lies in the fact that some houses have their lamp circuits wired for 50 volts pressure, and others for 100 volts pressure. If now, the coils of each of the two separate circuits of such a transformer, having a pressure of 50 volts, are so arranged that the current passes from one secondary coil through the next in succession, so that the two coils are connected as though they formed an unbroken winding, then their E. M. F.'s will be added, making a total of 100 volts. On the contrary, if it be desired to use a pressure of but 50 volts, then the two coils are employed side by side, or so connected to the house wires that each of the coils supplies half the current delivered. Such connections are shown in Fig. 37.

At *A*, 100 volts are obtained for the secondary circuit by connecting the two coils *in series*, as it is called, so that the arrows represent the direction of the current at some particular instant. At *B*,

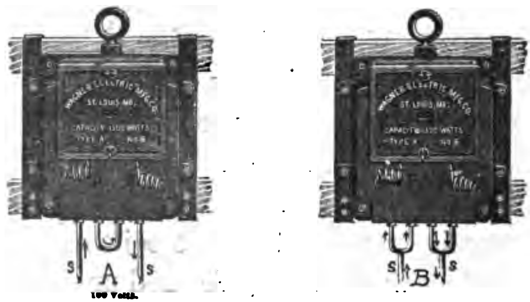


FIG. 37.—METHOD OF CHANGING SECONDARY CONNECTIONS.

50 volts are obtained by the *parallel* connection of two coils, or, as it is sometimes called, by their connection *in multiple*. If at *A*, the transformer is delivering 10 amperes at 100 volts pressure, or 1000 watts, at *B*, it will be delivering 10 amperes in

each coil, or 20 amperes in all, at 50 volts pressure, and, therefore, also 1000 watts.

In Fig. 31, the capacity of the transform-

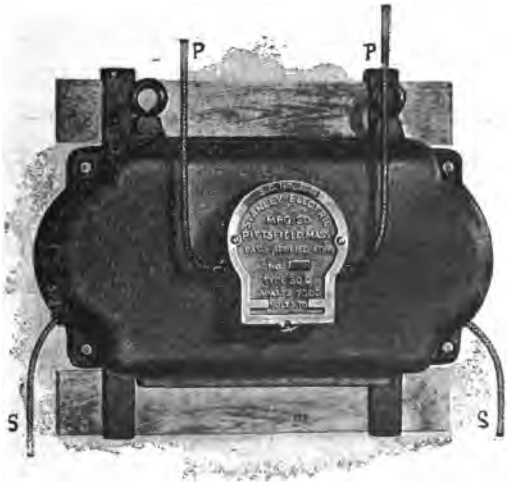


FIG. 38.—OUTDOOR TYPE OF TRANSFORMER.

er represented is 600 watts, or such as is capable of furnishing current for operating 12 fifty-watt lamps. That in Figs. 33 and 34, 5000 watts, or 100 such lamps.

A still larger transformer of 7500 watts capacity, or capable of operating 150 fifty-watt lamps, is represented in Fig. 38. This particular transformer is not insulated with oil, but depends upon the insulating covering of its coils for protection, the free space within the cover or iron shield being filled with air.

The current required to supply a transformer at full load may readily be ascertained when the primary pressure is known. For example, in the case of a 7500-watt transformer, if the primary pressure is 1000 volts, the primary current must be 7 1-2 amperes (1000 volts × 7 1-2 amperes = 7500 watts), if we assume that the *primary power factor* is 100 per cent. and that no loss occurs in the transformer. Strictly speaking, the power factor, even at full load, is not quite 100 per

cent., and a little loss of energy occurs in the transformer; *i.e.*, the transformer becomes warm in doing its work, so that the current strength supplied from the primary circuit at full load must be somewhat in excess of 7 1-2 amperes.

FIG. 39.—500-LIGHT TRANSFORMER, INDOOR TYPE.

A form of 25,000-watt transformer (25 KW. or about 33 H. P.) intended for 500 fifty-watt, 16-candle-power incandescent lamps, is represented in Fig. 39. This transformer is intended to be located in a cellar, or other suitable place within doors.

It will be seen that as the capacity of the transformer increases; *i. e.*, as the transformer has to supply more and more power, its dimensions increase, but not in the same proportion as the increase in capacity; so that if a 1 KW. or 20-light transformer weighs, in its case complete, 140 pounds, or gives 7 watts per pound of total weight, a 25 KW. transformer will, probably, weigh only 2000 pounds, or give 12 1-2 watts per pound, while a 200 KW. transformer will, perhaps, give 25 watts per pound, and a 1200 KW. transformer 100 watts per pound. It is much cheaper, per kilowatt of output, to construct transformers in large sizes.

When a step-down transformer is employed to reduce the pressure in a building from 1000 to 100 volts, it is clear that at the central station supplying the mains

leading to the building a generator must be employed of 1000 volts E. M. F. or more. This is commonly the case, and alternating-current generators in the U. S. generally produce either about 1000 or 2000 volts effective at their terminals. When, however, the current has to be transmitted over lines of great length, and it is necessary, for purposes of economy in conductors, to employ much higher pressures, say 10,000 volts, it is desirable, both on the score of safety and economy, to employ a step-up transformer, supplied by the generator at a lower pressure, rather than to endeavor to construct a generator to directly develop such pressure. In such cases, of course, these step-up transformers would be connected directly to the alternator terminals.

Large step-down transformers, intended

to supply an extended system of mains, are frequently installed in a small sub-station, for which reason they are sometimes

FIG. 40.—SUB-STATION TRANSFORMER.

called *sub-station transformers*. Since such transformers may take the entire load of a large alternator, they necessarily re-

quire to be of considerable dimensions. A form of such transformer is shown in Fig. 40, its length being about 6 feet. In designing such transformers care is taken to provide for the dissipation of the heat generated in their iron core and conductors when in action. Here the laminated core, consisting of large, thin sheets of iron, forming the frame or body of the apparatus, *CC*, is closely linked with the coils, *c*, *c*, *c*, *c*. The whole apparatus is carefully ventilated to permit of the free access of air and the insulation of the coils carefully preserved by means of sheets of mica.

Another advantage secured by the use of a few large transformers in place of a number of smaller ones is a greater efficiency. A large transformer in the course of its daily duty will probably supply, to its secondary circuit, 96 per cent. of the energy it receives at its primary terminal,

only 4 per cent. being lost in the transformers. The same amount of power being distributed by a number of small transformers might perhaps result on the average to a delivery of 80 per cent. and a loss of 20 per cent. In other words a small transformer wastes proportionately more energy than a large one.

CHAPTER VI.

ELECTRIC LAMPS.

HAVING examined in the previous chapters the method of generating alternating currents, the means employed for their distribution, and the apparatus by which their strength can be varied, it remains to discuss some of the different types of electric apparatus to which such currents are supplied. These are of a variety of forms, but the most important, at the present time, are lamps and motors.

When an electric current is sent through a conductor of high-resistance and small cross-section, so that a considerable amount of electric energy is expended in a small mass of material, the conductor is

heated, perhaps, to the temperature of luminosity, when it will emit light and heat. This is the principle on which an incandescent electric lamp is operated; a short thin filament or thread of carbon forming the high-resistance conductor.

The carbon filament acquires its high temperature in a fraction of a second after the current has been sent through it, as can be determined by observing the time which elapses from the closing of the circuit by turning the key or switch of an incandescent lamp until the lamp gains its full incandescence. In the same manner, on the interruption of the current by the opening of the circuit, an equally short time is required for the lamp to lose its brilliancy especially in slender filaments.

In an alternating-current circuit, the current not only changes its strength but

also changes its direction, during the different parts of an alternation. Consequently, twice in each cycle, at the moment when the change of direction occurs, there can be no current in the circuit, as will be evident from an inspection of Fig. 6. When alternating currents are supplied to incandescent lamps at a frequency of 100 cycles per second, it is evident that 200 times in each second there is no current passing through the lamp. It might, therefore, be supposed that the lamp would go out and be relighted 200 times a second. In reality an incandescent lamp tends to do this, and would do it were it not for the fact that the intervals of cessation of current are so brief that the lamp has not sufficient time in which to appreciably cool down, so that such changes of temperature as do occur, are not visible to the eye, and the lamp does

not visibly flicker. In order, however, to obtain this absence of flickering a certain frequency of alternation is necessary; for, it is evident that if the frequency becomes very low, sufficient time will elapse, between the current waves, to permit the carbon to sensibly decrease in brightness, thus permitting the retina of the eye to retain the impression of flickering. It has been found, in practice, that flickering in an incandescent lamp does not occur when the frequency of the alternation exceeds 30 to 35 cycles per second. In practice, in the United States, alternators for incandescent lighting are usually designed to produce a frequency much higher, say from 125 to 135 cycles per second.

When the energy from an electric current is utilized in an incandescent lamp, by far the greater part is uselessly ex-

pended in producing heat, or *non-luminous radiation.* It has been found that a comparatively slight increase in temperature will cause a marked increase in the amount of light emitted by a glowing filament. Consequently, the *commercial efficiency* of a lamp that is its ability to convert electrical energy into light energy, will be greatly increased, by any circumstance which will safely permit of an increase of temperature of its filament. This can readily be shown by applying successively increasing pressure or voltage to the terminals of a lamp, and so causing greater current to flow through it, the increase in the current being followed by a marked increase in the amount of light given off. Were it possible to double the ordinary working temperature of the filament of an incandescent lamp, without destroying it, we would very markedly in-

cease its light-giving power. In point of fact even a slight increase above the ordinary temperature produces a great increase in the brilliancy of the lamp.

But while an improvement is thus obtained in the light-giving power of a lamp, the *life of the lamp*, or the number of hours during which it will continue to give out this light, is greatly diminished. The problem for increasing the efficiency of an incandescent lamp has, therefore, been to obtain a conducting substance which would continuously stand a high temperature. Carbon is the only substance which has, thus far, been found available for commercial use. There is a certain temperature at which it is found most economical to operate carbon filaments, both in regard to their amount of light and duration of life. Below this tem-

perature, while the life greatly increases, the candle-power rapidly falls off. An incandescent lamp, burning at dull red temperature, will have an indefinitely long lifetime, while a similar lamp, operated at the ordinary temperatures commercially employed, will burn from 600 to 1800 hours.

Since the filaments of incandescent lamps are made of various lengths and cross-sections, or, in other words, since their filaments have varying electrical resistances, the pressures required to produce in them the requisite temperature will necessarily vary. In practice, lamps are constructed which require pressures varying from 2 volts to 250 volts. *High-pressure lamps*, of any given candle-power, have long, thin filaments, while *low-pressure lamps*, of the same candle-power, have short thick filaments.

Various forms are given to incandescent lamps, but all consist essentially of the same parts; namely, an *incandescing filament* of carbon placed in an exhausted *glass chamber* and connected with the cir-

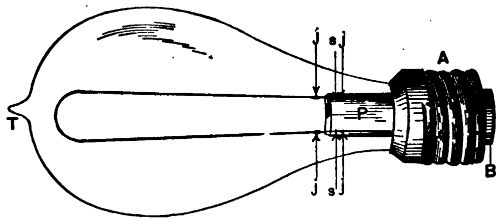


FIG. 41.—16-C.P. INCANDESCENT LAMP.

cuit by a *socket*, the wires leading the current into the lamp being automatically connected with the circuit by the act of inserting the lamp in its socket.

Some forms of incandescent lamps are shown in Figs. 41, 42, 43 and 44. Fig. 41 is a form of 16-candle-power lamp in extensive use, consisting of a filament bent in a

single loop. The *lamp base* is provided with a screw thread for insertion in the

FIG. 42.—INCANDESCENT LAMPS AND SOCKET.

screw socket. Fig. 42 represents another form of lamp, in which the screw thread is

FIG. 43.—INCANDESCENT LAMPS.

in the interior of the base, instead of on the external surface. This figure

also shows a lamp inserted in the socket which is provided with a key *K*. Figs. 43 and 44 show another form of incandescent

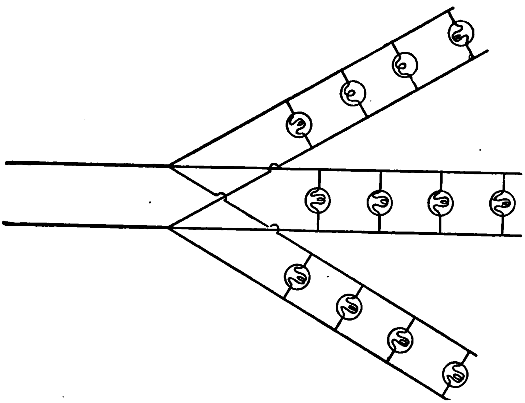
FIG. 44.—INCANDESCENT LAMPS.

lamp furnished with different bases; *a* is intended to give 10 candle-power, *b*, 16 candle-power, *c*, 20 and *d*, 32.

All the incandescent lamps here shown are equally applicable for use on continuous or alternating-current circuits. In practice, where the area of distribution to consumers is not great, the continuous current is usually employed, but where the area of distribution is large, and the lighting scattered, it is usually more economical to use alternating currents in connection with step-down transformers.

Incandescent lamps as supplied from step-down transformers are always connected *in parallel*, that is, the lamp's terminals are connected across the mains as shown in Fig. 45, which represents a *two-wire system of distribution*. Sometimes,

however, the lamps are connected as shown in Fig. 46, where the 20 lamps shown are connected between three wires of the *three-wire system of distribution* represented.



Two wire S

Fig. 45.—Two-Wire System of Multiple Connected Lamps.

In cases, however, where incandescent lamps are required for street lighting over an extended area, where the lights are, therefore, scattered, the systems of dis-

tribution shown in Figs. 45 and 46, are too expensive, and it is also too expensive to employ a special or separate transformer for each lamp post. In this case the method of distribution sometimes

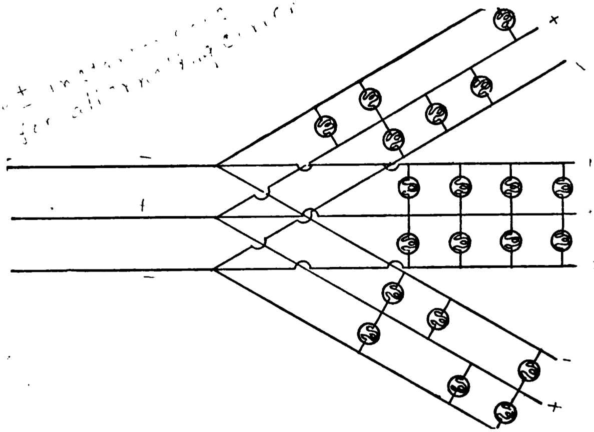


FIG. 46.—THREE-WIRE SYSTEM OF MULTIPLE CONNECTED LAMPS.

employed is that represented in Fig. 47, where the lamps are connected *in series*, the current passing successively through

each lamp. In the method of distribution shown in Figs. 45 and 46, the failure of any one of the lamps to operate, as, for example, by the breaking of its filament,

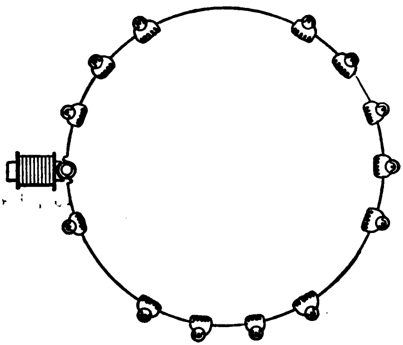


FIG. 47.—SERIES DISTRIBUTION OF INCANDESCENT LAMPS WITH ALTERNATING CURRENTS.

does not affect the supply of current to the other lamps. When, however, the lamps are connected in series, the discontinuity of one lamp would open the entire circuit were it not for the small *choking*

coil which is placed as a shunt or by-path to each lamp. While the circuit is maintained through the lamps, very little current passes through the choking coil, so that the waste of current and energy through the latter is very small. If, however, the lamp breaks its circuit, the choking coil carries the current without appreciably affecting the supply to the rest of the lamps in the circuit. These choking coils are represented in Fig. 47 as being connected around the terminals of each lamp. Fig. 48 represents such a street lamp with its choking coil. Here the lamp is provided with an external shade and globe to protect it from the weather. Fig. 49 gives a more complete view of the choking coil.

Alternating currents are also employed for arc lighting. As in the case of incan-

descent lighting, in order to prevent the variations in the current strength from producing marked flickering in the light, a certain frequency is necessary. It has been found in practice that the arc lamps

FIG. 48.—COMBINED FIXTURE AND REACTIVE COIL.

will show no disagreeable flickering if the frequency exceeds 45 cycles per second.

Alternating-current arc lamps do not differ in general construction from continuous-current arc lamps, save in the details

of their regulating mechanism. Since, however, the upper and lower carbons be-

FIG. 49.—STREET LAMP REACTIVE COIL.

come alternately positive and negative, the rate of consumption of each carbon is sensibly the same. A form of arc lamp,

FIG. 50.—ALTERNATING-CURRENT ARC LAMP.

suitable for use for an alternating-incandescent circuit of either 50 or 100 volts pressure, is shown in Fig. 50. In circuit

FIG. 51.—REACTIVE COIL OR COMPENSATOR FOR ARC LAMPS ON ALTERNATING-CURRENT CIRCUIT.

with the lamp or lamps is connected a choking coil or *compensator*, as shown in Fig. 49, whose object is to regulate automatically the amount of current passing through the lamp.

CHAPTER VII.

ELECTRIC MOTORS.

It is a well-known fact that when a continuous electric current passes through a continuous-current generator at rest, the generator will be set in motion. The early history of this discovery still remains in some doubt. It is claimed that the first observation of this power of a dynamo to act as a motor, or, in other words, this *reversibility of the dynamo*, was the result of an accident, which occurred during the Vienna Exhibition of 1873, when the current of one generator was accidentally led through the circuit of a second generator. According to, perhaps, more credible accounts, this property was the direct result of research in 1867. However this

may be, the first dynamo that was ever publicly exhibited running as a motor, from the current supplied by a similar dynamo, was at the opening of the 1873 Vienna Exhibition.

It is a well-recognized scientific principle that work is never lost or. in other words, that the total amount of energy existing in the universe is constant. Work may be made to assume different forms, but can never be annihilated. When, for example, mechanical work is expended in driving a dynamo, apart from certain expenditures, all this work is transformed into electrical work. When this electrical work is properly applied to the armature of another generator standing at rest, the electrical work is transformed into mechanical work, as is evidenced by the ability of the motor to drive machinery. We

have seen that a horse-power is equal to an activity of 746 watts. Consequently, if the electric motor were a perfect machine; *i. e.*, wasted no power, it would take 746 watts, from the circuit supplying it, for every horse-power it exerted in its work; and, if operated at a pressure of 100 volts at the mains, would, therefore, receive 746-100=7.46 amperes, per horse-power delivered. Owing to the necessary losses of energy in the motor, a greater current strength than this will in practice be needed, perhaps, 10 amperes, depending, however, upon the size of the motors. Large electric motors frequently possess a very high *efficiency; i. e.*, their *output* in mechanical work is very nearly equal to their *intake* in electrical work. Since, as we have seen, a motor can readily be driven at a long distance from the generator supplying it, is evident that the *elec-*

trical transmission of power possesses marked advantages. An example of a continuous-current motor is shown at Fig. 52.

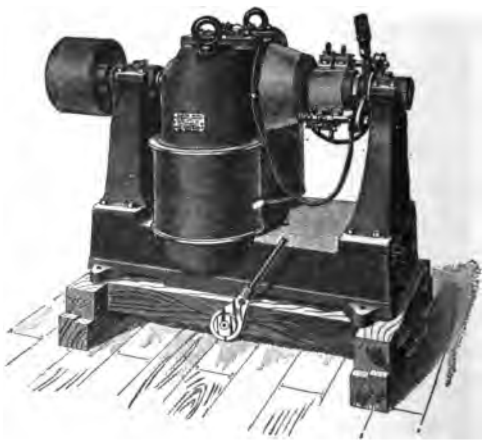


Fig. 52.—Continuous-Current Stationary Motor

If two continuous-current generators, similar in all respects, be electrically connected by a circuit say one mile in length, one being driven by a steam engine as a generator, while the other is

running at the same speed as a motor, then, as we have already seen, the current is alternating in the armature of each machine, but, owing to the action of the commutator, is continuous in the line between them. Assuming the two machines to be running at the same speed, if the commutators are suddenly removed from each, the two machines will continue running, though the current on the line, as well as the current through the armatures, will now be alternating. The two machines, which must now be regarded as alternating-current machines, will still be acting as generator and motor, or as the driving and the driven machine.

In this respect, therefore, continuous and alternating-current dynamos are alike; since, in either case, one acting as the generator can drive the other as the

motor. They differ, however, in this respect, that, whereas, in the case of the continuous-current circuit, the motor will start from a state of rest, and can be driven either at the same speed as the generator or at different speeds; in the case of the alternating-current circuit, the motor will not start from a state of rest and can not be operated until it has been brought up to the same speed as the generator; or, as it is usually termed, until it has been brought *into step* with it. Once the motor has been brought up to the speed of the generator, it can, if well designed, be made to take its full load mechanically and electrically, without falling *out of step*. Since such an alternating-current motor will not operate unless it is running at the same speed as the driving alternator, it is called a *synchronous motor*.

When synchronous motors are employed, it is, therefore, necessary to devise some means whereby they can be brought up to their normal speed before they are connected with the circuit sup-

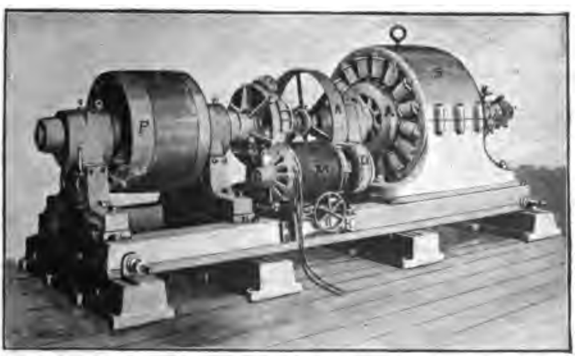


FIG. 53.—250-H.P. ALTERNATING - CURRENT SYNCHRONOUS MOTOR.

plying them. Various devices have been proposed for this purpose. The one in most general use is that shown in Fig. 53. Here the synchronous alternating-current

motor *S*, of 250 H. P., is intended to drive machinery by the pulley *P*, through the clutch *C*. In order to start the motor, the clutch is opened, and a small motor *M*, called a *diphase motor*, which will be described in a subsequent chapter, is operated, and drives the large motor armature through the friction pulleys *Q* and *R*. As soon as the armature *A*, has, in this way, been brought up to speed, the small motor *M*, is disconnected, and the armature *A*, is connected with its circuit, when it takes alternating currents, and is ready to receive its load as a synchronous motor. The clutch *C*, is then thrown in, rigidly connecting the motor shaft with the driving pulley *P*. Finally, the small driving motor *M*, is moved back by the handle *H*, so that its pulley *Q*, is out of contact with the pulley *R*. The armature *A*, receives its current through the contact

rings G, G, at the end of its shaft, and, by means of the commutator K, supplies the continuous currents required for the excitation of its own field magnets, in the same manner as though it were a self-excited generator.

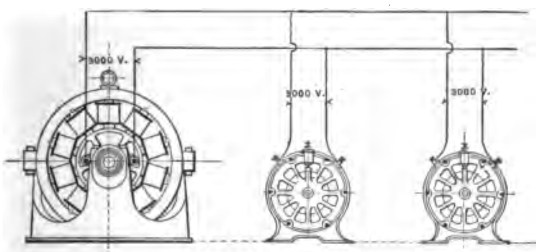


FIG 54.--ALTERNATOR WITH SYNCHRONOUS MOTORS.

Fig. 54 represents a 3000-volt alternator, suppling two synchronous motors directly from the same pair of mains, the starting motors not being shown. The pressure at the brushes of these motors is marked as being 3000 volts effective,

representing about 4200 volts at the peak of each alternation of pressure.

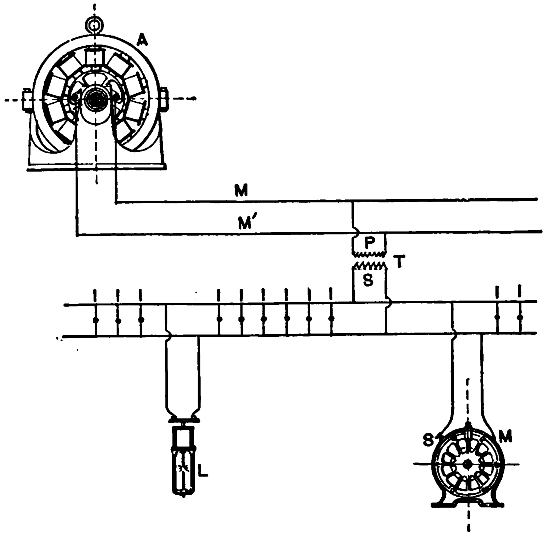


FIG. 55.—ALTERNATOR WITH TRANSFORMER AND ITS SECONDARY CIRCUIT.

Fig. 55 represents an alternator *A*, supplying a pair of high-pressure mains *M*, *M*, and a primary coil *P*, of a transformer *T*,

whose secondary coil is connected to the arc lamp *L*, incandescent lamps *I*, *I*, and a synchronous motor *SM*, all operated in parallel.

It is evident that since a synchronous motor has only one speed of rotation and requires some appreciable time to start from rest by auxiliary means, that it is unsuited to machinery which requires to be operated at varying speeds and for intermittent periods. For all purposes, however, where the power is required continuously, or for many hours a day at a steady rate, as, for example, in pumping or driving large counter shafts in a machine shop, the synchronous motor is a very useful machine,

Up to the present time no single-phase alternating-current motor, of say more

FIG. 56.—ONE-EIGHTH H.P. ALTERNATING-CURRENT FAN MOTOR.

than half a horse-power in capacity, has yet been produced in the United States, which is capable of starting at full load, from

FIG. 57 —ALTERNATING-CURRENT FAN MOTOR.

rest, on ordinary alternating circuits, and which will run with a reasonable amount of economy. There are, however, a num-

ber of small alternating-current motors, some of which operate with the aid of a commutator, as, for example, the fan motor, shown in Fig. 56. Here the current through the fields is reversed at every alternation of the alternating current, but by means of the commutator, the effect of this reversal of magnetism is reversed upon the armature current, and a continuous magnetic pull produced. Unfortunately the efficiency of such machines is comparatively small, so that they are only capable of being employed in small sizes, where economy is not of much importance. Another form of alternating-current motor of this type is seen in the fan motor shown in Fig. 57.

CHAPTER VIII.

MULTIPHASED CURRENTS.

THE difficulty pointed out in the last chapter, as regards the starting of synchronous motors, has led to a special development in alternating-current apparatus called *multiphase apparatus.* The *synchronous motor* is supplied by a single alternating current. The *multiphase motor* is supplied by more than a single current. In practice either two or three currents are employed for driving multiphase motors, thus giving rise to *diphase motors*, which are supplied by two separate alternating currents, and *triphase motors*, which are supplied by three separate currents. *Multiphase motors*, therefore, require special generators for the production of the

currents they employ. We shall now proceed to discuss the construction and operation of diphase and triphase generators.

It must first be remarked that in a di-

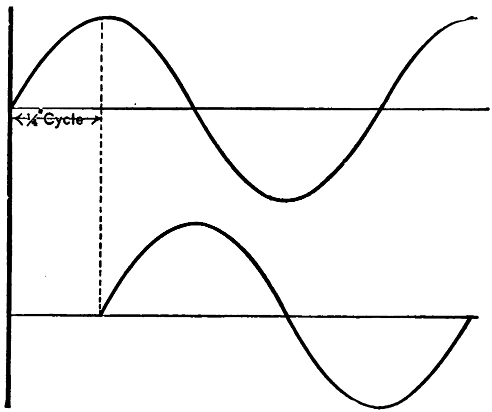


FIG. 58—RELATION BETWEEN TWO DIPHASE ALTERNATING CURRENTS.

phase motor, for example, it is not sufficient to simply supply to the motor any two, separate, alternating currents. The

proper operation of the motor requires that the two separate currents shall possess a certain relationship to each other; namely, that one shall be a quarter of a cycle in advance of the other, as shown in Fig. 58. A *diphase generator*, therefore, must be constructed not only so as to produce two equal separate alternating currents, but these alternating currents must also have a quarter of a cycle of *phase difference* between them. Such a condition will enable the motor to start, as well as to preserve a uniform pull or *torque* upon its driving shaft.

A diphase motor is driven by two separate series of electrical impulses one quarter cycle apart. This condition finds an analogue in the ordinary steam locomotive, which, as is well known, is driven by two separate steam cylinders placed on

opposite sides of the driving engine. In the early history of the steam locomotive, when but a single cylinder was used, it was found, at times, that the engine could not be started from a state of rest, since it had stopped on a dead centre, and required, like the synchronous motor, to be started before it could by driven. This difficulty, as is well known, is now obviated by the use of two pistons, set at a quarter of a cycle, or 90° apart.

In order to obtain two separate alternating E. M. F. 's, a quarter cycle apart, in two separate circuits, either two separate windings are employed on a single armature, or two separate armatures are rigidly connected and driven on the same shaft. The latter method is represented in Fig. 59, where a 750 KW. or 1000 H. P. diphase generator is shown. This genera-

tor consists of two complete *uniphase generators A* and *B; i. e.*, generators of the ordinary single alternating-current type,

Fig. 59.—750-Kilowatt Columbian Exposition, Diphase Alternator.

rigidly connected together in such a manner that the armature of one machine is just far enough ahead to produce its alter-

nating E. M. F. a quarter of a cycle in advance of that of the other. This machine is compound-wound, supplying its field magnets partly from the commutator *C*, and has three collector rings *R*, *R*, *R*, one of the outside rings for each current and the middle ring, as a common con-

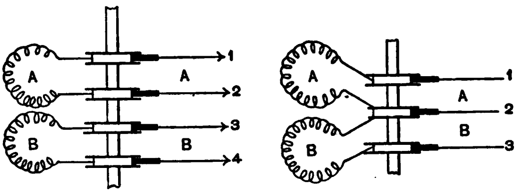


FIG. 60—DIAGRAM SHOWING THE TWO METHODS OF CONNECTING DIPHASE ARMATURE WINDINGS THROUGH COLLECTIVE RINGS WITH EXTERNAL CIRCUITS.

nection for both, as shown in Fig. 60. The belt tightening handle is shown at *H*.

Another form of diphase generator is shown in Fig. 61. Here a single armature has two windings, the E. M. F. in one of which is developed a quarter of a cycle

before the other. The three conductors *A*, *B*, *C*, carry off the two diphase currents, while the conductors *F*, *F*, supply

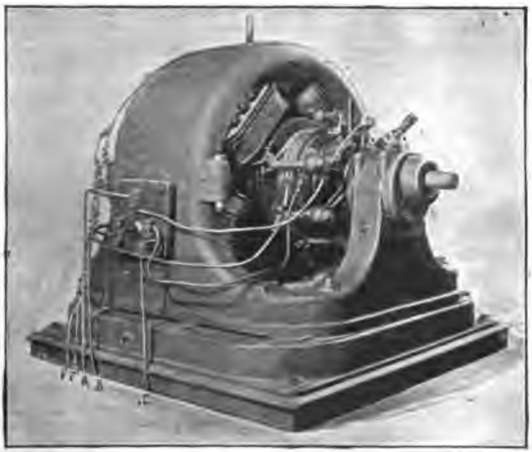


FIG. 61.—100-KILOWATT MULTIPHASE GENERATOR.

the field with a continuous current. The commutator *C*, supplies current to the field magnets.

Another form of diphase generator is

represented in Fig. 62. Here two separate external armatures *A* and *B*, do not revolve, while within them revolves the field magnet driven by a pulley *P*. The

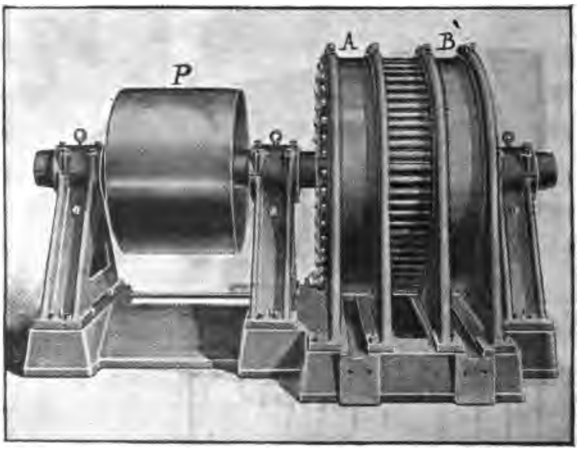


FIG. 62.—DIPHASE ALTERNATING-CURRENT GENERATOR.

E. M. F. in one armature, say *A*, is developed a quarter of a cycle, or half an alternation, ahead of that in *B*.

The circuits of such a diphase generator require, as shown in Fig. 60, either three or four wires. If four wires are employed, the two separate circuits are entirely distinct, while if three wires are employed, one of the conductors is common to both circuits.

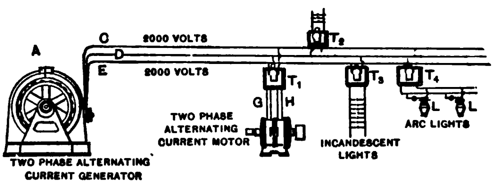


FIG. 63.—DIPHASER AND ITS CIRCUIT.

In Fig. 63, a diphase generator or *diphaser* is represented at A. The two separate currents, generated in this machine, are led to the transformers T_1, T_2, T_3, T_4, through the three wires of the circuit. The pressure at the generator brushes is 2000 volts effective, beween C and D, or between D and E. The transformers T_2,

T_3 and T_4 are connected between a single pair of wires; namely, T_2, between C and D, T_3 between D and E, and T_4 between D and E, so that only one current is supplied to each of these transformers. In all cases, where diphase currents are not to be used simultaneously in a motor, they are separately used as uniphase currents either in lamps or in synchronous motors. T_4 is a transformer on one of the circuits supplying arc lamps L,L, at a pressure of, perhaps, 50 volts. The transformer T_1, which is really a double transformer, half between the wires C and D, and half between the wires D and E, supplies in its secondary circuits G and H, diphase currents to the diphase motor M.

A *triphase generator* or *triphaser* is a generator which produces three separate alternating E. M. F.'s separated from each

other by one third of a cycle, as represented in Fig. 64. Such a machine is shown in Fig. 65. Here the armature has three separate windings upon it, so arranged that the E. M. F.'s generated in

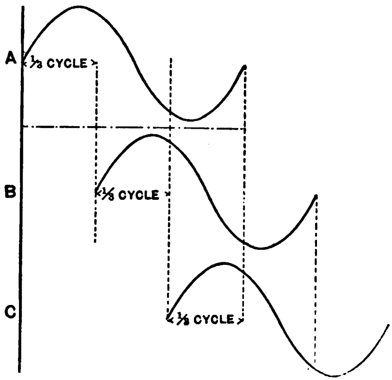


FIG. 64.—DIAGRAM REPRESENTING PHASE RELATION OF TRIPHASE WAVES OF E. M. F. AND CURRENT.

them succeed each other by one third of a cycle. Three collector rings R^1, R^2, R^3, on the right hand armature on the shaft, carry off the current as shown in Fig. 66, to three wires, AA^1, BB^1, CC^1, each of

which serves as a return circuit for the other two.

The motor windings, transformers, or other devices are connected between the

FIG. 65.—500-KILOWATT TRIPHASE GENERATOR.

wires as at $A^1 B^1$, $B^1 C^1$, or $C^1 A^1$. Triphasers possess electrical features which have gained for them considerable favor. A triphaser only requires three wires for its

three currents. A diphaser requires four wires but can be operated with three.

Beside the diphase and triphase generators another system has come into recent

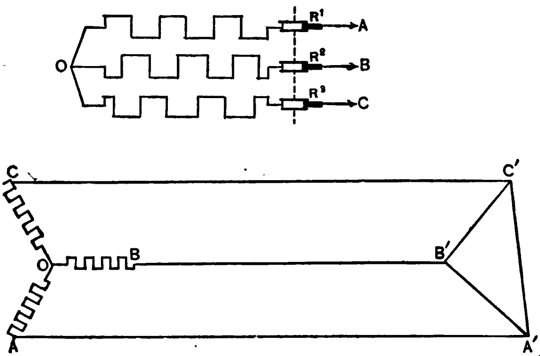


FIG. 66.—DIAGRAMS REPRESENTING CONNECTIONS OF TRIPHASE WINDINGS WITH THEIR EXTERNAL CIRCUITS.

favor, called the *monocyclic system.* The *monocyclic generator*, or *monocycler*, is primarily a uniphase generator, and is intended principally for the delivery of ordinary alternating or uniphase currents,

over a system of electric lighting mains. In order, however, to supply starting alternating-current motors wherever they may be installed in the system, a special series of coils, of smaller size and cross-section, is placed on the armature so as to produce a small E. M. F. a quarter cycle out of step with the main uniphase E. M. F. This smaller E. M. F. is connected to a third collector ring on a special circuit wire, called the *power wire*, which has a smaller cross-section than the main uniphase wires, and is led only to where the motors are to be used. By the use of two transformers, connected with the power wire and the main wires, triphase E. M. F.'s are produced in a secondary circuit for the operation of triphase motors, while between the main wires in all other parts of the system, ordinary uniphase E. M. F.'s are maintained.

A form of belt-driven 150 KW. monocyclic generator is represented in Fig. 67. Here the three collector rings are shown

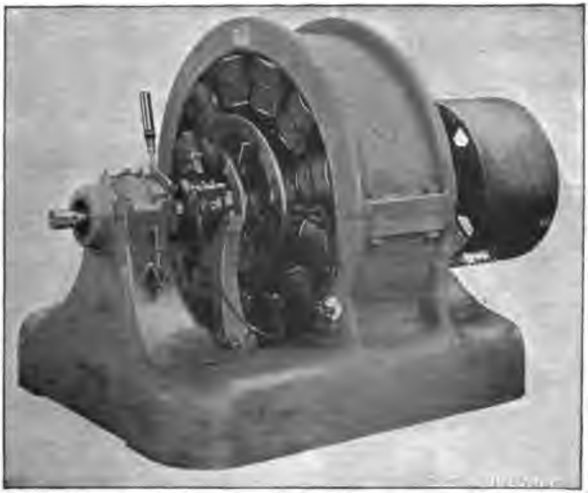


FIG. 67.—150-KILOWATT MONOCYCLIC GENERATOR.

at *R*, *R*, *R*, and the commutator *C*, is for the compounding of the field magnets. Fig. 68 represents the armature of such a

machine, with its three collector rings and its commutator. It is often found difficult to determine, from the appearance of such a machine, whether it is of the monocyc-

FIG. 68.—MONOCYCLIC ARMATURE.

lic, diphase, or triphase type, but a close inspection of the armature will usually indicate that the main coils *ZZ*, *AA*, *BB*, are larger than the intermediate coils or lesser coils *T*, *T*, *T*, *T*, *T*, *T*.

CHAPTER IX.

MULTIPHASE MOTORS.

PRIOR to the introduction of the multiphase machinery there were but two methods whereby electric power could be commercially transmitted over a considerable distance; namely, either by the use of continuous-current motors, or by the use of synchronous alternating-current motors. As we have already pointed out, in order to obtain the advantages of the electrical transmission of power it is necessary to employ a high pressure on the conducting line so as to save copper in the conductor. While this is possible by the use of continuous-current motors, and, in point of fact, has been employed, yet the presence of commutators, which

such a system necessitates, both on the generator and motor, has been found, in practice, to give rise to no little risk and trouble, since the total pressure between the lines, being thus brought directly to the opposite sides of the commutator, should an arc discharge occur over the commutator, there would be a danger of its destruction.

In order to lessen these difficulties, the plan has been tried of distributing the line pressure to a number of motors all rigidly connected to the same shaft, and traversed successively by the driving current. If, under a line pressure of say 2500 volts, five motors were so coupled together, then each motor would receive a pressure of one fifth of the total, or 500 volts. Although this device reduces the pressure across each commutator, yet the insulation of each machine has to be carefully main-

tained, since, otherwise, a discharge might take place through the commutators to the shaft, under the whole pressure of the line, thus disabling the plant. Consequently, early in the history of alternating currents, appreciating the advantage in practice, arising from the absence of a commutator, the uniphase generator and motor were connected, by means of conducting lines, for power transmission. To a certain extent this combination was successful; for, as has already been pointed out, beside the advantage of collecting rings instead of commutators, the system possessed a marked advantage from the ease with which the pressure could be varied by the aid of suitable transformers. When the line pressure is too high to employ safely at the brushes of generator and motor, these latter can be constructed for lower pressures and larger currents, and then,

by the use of step-up transformers at the generator, and step-down transformers at the motor, all the advantages of high pressure in the line, and low pressure at the machinery, can be secured, without great additional risk or cost. Such a system of transmission, however, necessitates the employment of the uniphase synchronous motor, and was, therefore, totally unfitted to cases where the motor had to be frequently stopped and started.

Happily these practical difficulties in the commercial transmission of power have been removed by the introduction of multiphase alternating-current apparatus, and while it is true that the use of such apparatus necessitates the employment of at least one additional conductor, yet the advantages possessed by the multiphase system are so considerable, that even al-

though this conductor involved extra cost in the copper, yet the advantages obtained would render its adoption economical. In point of fact, however, the amount of copper actually required for the three-wire multiphase system is one fourth less than that for the same amount of power by the uniphase system employing the same pressure in the line.

As at present employed multiphase currents are readily divisible into diphase, triphase, and monocyclic. Consequently, it will be convenient to treat motors under the same general heads. In point of fact, however, the difference between these forms of motors is comparatively trivial. A diphase motor differs from a triphase motor mainly in the fact that it has two circuits in its fields instead of three.

In order to understand the operation of any multiphase motor, we will consider the effect produced on a suitable field-winding when multiphase currents are supplied to it. It is necessary to remember that two separate alternating currents, flowing through two separate circuits, do not form a diphase system, unless the two currents differ in phase by a quarter cycle, or are 90° apart. When such diphase currents are sent through properly wound field frames, they tend to produce in them a magnetic field of a curious character; namely, the poles produced do not only alternate in direction with changes in the direction of the current, but act as though the field rotated. For example, if in Fig 69, we consider the pair of coils 1, 3, on the opposite sides of the field frame, and suppose that a single uniphase current is supplied to them, it is evident, that if dur-

ing any wave of current the pole 1 is a north pole and 3, a south pole, then during the next wave of reversed current, these poles will be reversed or 1 will be

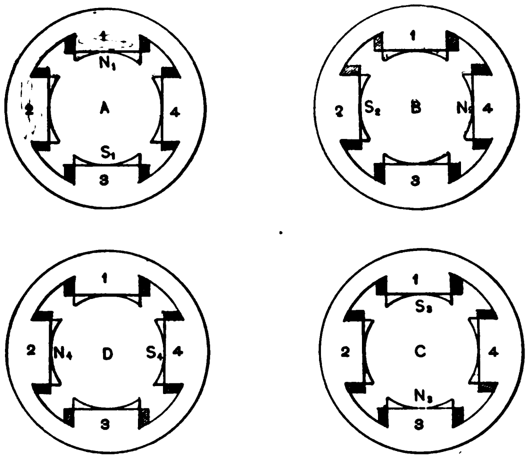


Fig. 69.—Diagrams Illustrating Effective Rotation of a Diphase Magnetic Field.

south, and 3, north. The same conditions will be maintained in the adjacent poles 2 and 4, which are alternately north and south, and south and north. But if the

waves of current through *C* and *D*, come half an alternation later than the waves in *A* and *B*, we obtain a series of conditions represented; namely,

(A) 1 is north, 3 is south, while 4 and 2 are in transition, there being no current in them at that instant.

(B) In the next quarter cycle, 4 and 2 are now active, while 3 and 1 are in transition.

(C) At the next quarter cycle 3 and 1 have again come into action in the opposite direction, while 2 and 4 are in transition, and finally:

(D) In the fourth quarter of the cycle, 1 and 3 are in transition, while 4 and 2 are active. If, now, we examine these figures we shall see that the N. and S. poles have steadily progressed around the field frame in the direction of the hands of a clock, so that, although alternating currents have

been employed, yet by reason of their proper phase difference in the two separate circuits, their effect has been to cause the magnetic field to rotate. If a compass needle were introduced into the middle of the field frame, it would, if left free to spin around the axis, rotate about that axis at the rotary speed of the field; namely, one revolution per cycle. Such a rotating compass needle may be considered as a small armature capable of acting as a motor. A piece of soft iron pivoted upon an axis at the centre will revolve in the same way. In practice it is usual to construct a laminated armature core, like that of a continuous-current motor, wound with closed coils or closed loops, so as to induce powerful currents in these coils by the rotation of the magnetic flux through them, and thus develop a powerful magnetic attraction between the revolving magnetic field

and these currents. Such motors are therefore sometimes called *induction motors.*

In order to reverse the direction of a polyphase motor it is only necessary to reverse the direction of one of the windings on the motor, so as to reverse one of the pairs of poles, when the field will rotate in the opposite direction. With the apparatus actually employed a switch is arranged, so that, by its motion, one of the field windings is reversed.

A triphase motor differs from a diphase motor only in that its field windings contain either six coils, or some multiple of three, instead of four coils or some multiple of four. The effect of the current waves succeeding each other in the different windings, by one third of a cycle, produces a continuously rotating field.

Fig. 70 represents a 15 H. P. diphase motor. *FF* is the field frame of laminated iron with suitable windings inside to pro-

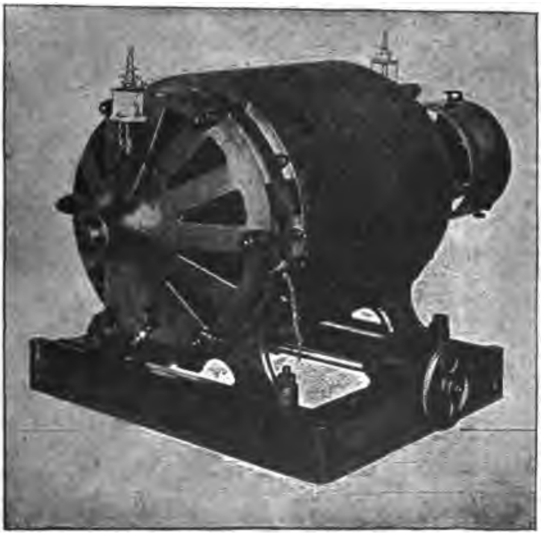


FIG. 70.—FIFTEEN-HORSE-POWER DIPHASE MOTOR.

duce the revolving field, within which the armature rotates driving the pulley *P*.

It is important to observe that in synchronous motors, the field frame need not be laminated, since the field poles do not change polarity, being excited by a continuous current, but in multiphase motors, since the field magnets are excited by alternating currents, it is important that the iron be laminated, in the frame as well as in the armature, since, otherwise, loss of power and injurious heating would occur.

Fig. 71 shows a form of triphase motor for 7 1-2 horse-power. The three conducting wires are led through the winding of the field to the terminals *A*, *B*, *C*, and the armature shaft has a series of contacts *C*, which is not a commutator, although somewhat resembling one in appearance. When the handle *H*, is in the position shown, certain resistances

are included in the circuit of the armature windings, so as to enable the motor to start from rest. It is found, that if the full pressure be supplied to the field of

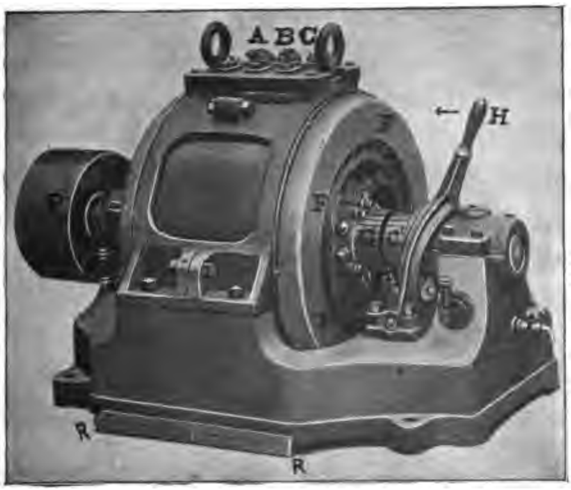


FIG. 71.—TRIPHASE INDUCTION MOTOR, 7½ H.P.

the motor with the armature in its ordinary short-circuited condition, such powerful currents are induced in the armature

as to weaken its starting power. By the insertion of extra resistance, however, these currents can be reduced to the proper strength in the armature circuits to obtain a powerful starting power or *torque*, and, when the machine has attained full speed, the handle is pushed in toward the field frame, thereby sliding the contact ring *C*, into the strong clips of C^1, short-circuiting the extra resistance, and cutting it out of circuit. The size of this motor is indicated by a foot-rule *RR*, shown at its base.

Fig. 72 represents a similar triphase motor for 125 H. P. The three terminals of the field winding are shown at the top of the frame *F*, *F*, *F*, *F*; within revolves the armature A, A, A. As in the last case, the handle *H*, when the motor has been brought up to speed, throws forward a

collar *K*, into a receptacle, thus cutting the *starting resistance* out of the circuit of

FIG. 72.—125-HORSE-POWER INDUCTION MOTOR.

the armature coils. It will be seen that these triphase motors are very simple in appearance, have self-oiling bearings, and,

having no commutator, require the minimum of attention.

Another form of small induction motor is represented in Fig. 73. This is a tri-

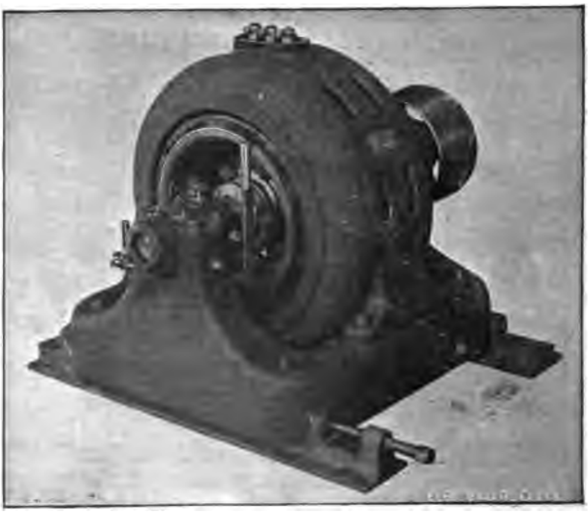


FIG. 73.—MONOCYCLIC MOTOR.

phase motor frequently operated on a monocyclic circuit.

Figs. 74 and 75 show a form of diphase motor, with front and rear view. The three collector rings R^1, R^2, R^3, are em-

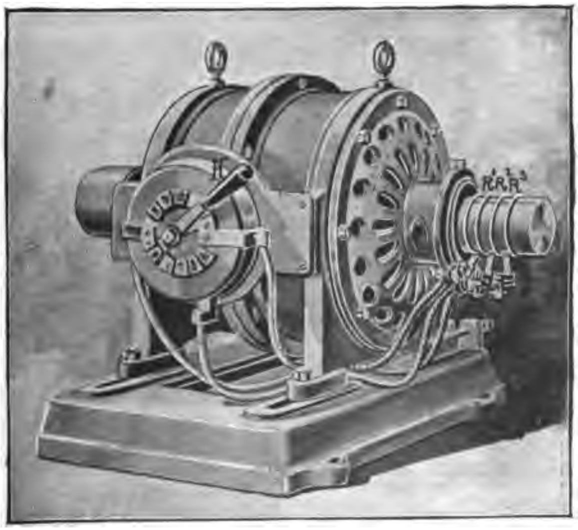


FIG. 74.—DIPHASE MOTOR.

ployed for the purpose of inserting resistance in the armature circuits under the control of the handle H, which is only

employed in starting the motor. As soon as full speed is reached, the additional resistance is entirely cut out of circuit.

The interior of the field frame for this

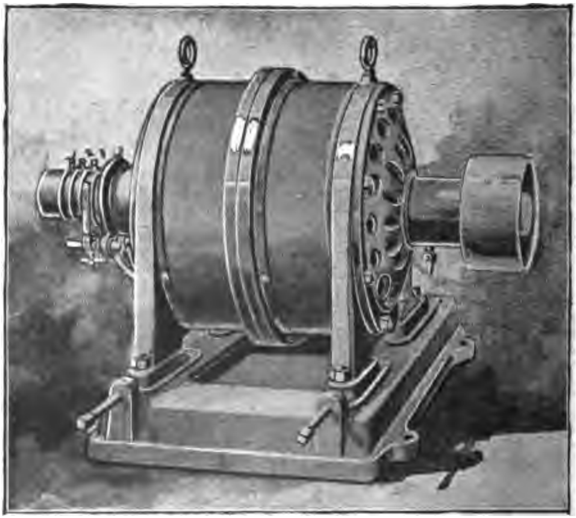


FIG. 75—DIPHASE MOTOR.

motor is represented in Fig. 76. It will be seen that there are two separate field frames placed side by side, but differing

in relative position. One of the two diphase currents supplies the series A, B, C, and the other diphase current, the series A^1, B^1, C^1. Under these conditions, al-

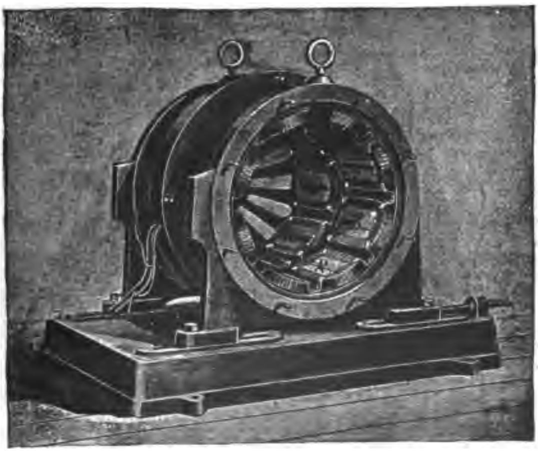


FIG. 76.—MOTOR FIELD.

though no rotating magnetic field is produced, yet by the effect of these alternating magnetic poles upon the armature, a rotating magnetic field is developed upon

it. The armature is represented in Fig. 77. At *A*, the core is shown, consisting of two separate halves H^1 and H^2, each revolving under one series of field magnets in the field frame. The appearance

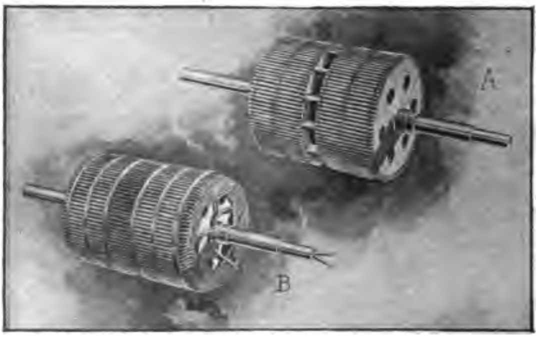


FIG. 77.—MOTOR ARMATURES.

of the armature after winding is shown at *B*, where the wire occupies the grooves between the iron teeth on the armature surface. The winding is carried completely across the double armature, so

that the currents produced in the winding by one series of field poles react upon the neighboring series. This motor is designed for a frequency of about 130 cycles per second. Triphase and diphase motors, while they can be designed for other frequencies, are more commonly employed at a frequency of 60 or 30 cycles per second.

The practical trend at the present time is toward the introduction of multiphase systems for the transmission of electric power. This tendency has resulted from the great flexibility possessed by multiphase systems.

Such, in brief, is a description of the more important commercial applications of alternating-current apparatus. When we consider that the developments in this latest field of electrical improve-

ment have occurred practically within less than a decade, we cannot but believe that the next decade will witness even still greater improvements in this rapidly-advancing art.

THE END.

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